RADC-TDR-63-181

MARCH 1963
REPORT NO. 3.469
Copy No.

Final Report

UNIVERSAL PRINT READER

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K. W. JENKNER R. E. KITTREDGE
J. F. KRIPL F. P. LEWANDOWSKI
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CONTRACT AF 30(602)-2642

PREPARED FOR

ROME AIR DEVELOPMENT CENTER
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
GRIFFISS AIR FORCE BASE
NEW YORK

LINK DIVISION
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FOREWORD

This report covers the results of study and experimentation directed toward the design of multifont optical scanning systems, following basic techniques previously conceived and developed, by Link, together with a description of demonstrable laboratory hardware constructed by Link as a prototype model in performance of a contract with a commercial customer and recommendations for further study and experimentation. This study contract was performed under contract with the Rome Air Development Center by Link Division, General Precision, Incorporated, Binghamton, New York. Study and experimentation was performed using an actual laboratory page reader termed the Model X-3, a production model of which is presently being constructed for delivery to Beneficial Management Corporation.

Principal contributors to the studies reported herein were:

Messrs. A. K. Dietrich
R. B. Greenly
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F. P. Lewandowski
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ABSTRACT

The objective of this program was to determine the potential capabilities of the Link Reading Technique toward fulfilling the requirements of a reading machine which could be appropriately referred to as "A Universal Print Reader." Emphasis was placed on development of paper handling capability as well as multi-font recognition since commercially available equipment in both areas falls far short of "universal" status. Results indicated that reliable multifont recognition can be realized and compatible paper handling mechanisms can be made which are tolerant of a reasonable amount of input document degradation such as is common with field prepared documents.

This report contains a detailed description of the operating principles of a complete Link page reading system, along with a number of techniques for extending the performance of this machine.

PUBLICATION REVIEW

This report has been reviewed and is approved.

Approved:
for FRANK J. TOMAINI
Chief, Information Processing Laboratory
Directorate of Intelligence & Electronic Warfare

Approved:
ROBERT J. QUINN, JR., Col, USAF
Director of Intelligence & Electronic Warfare

FOR THE COMMANDER:
IRVING J. GABELMAN
Director of Advanced Studies

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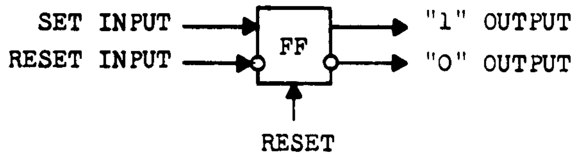

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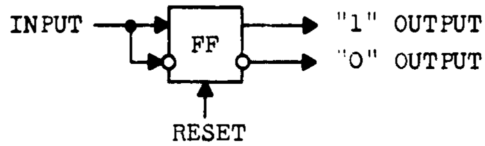

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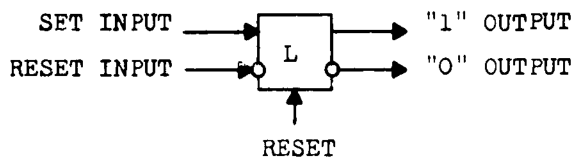

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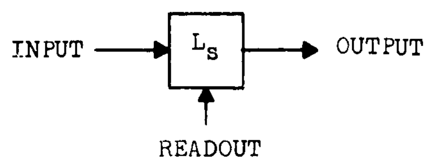

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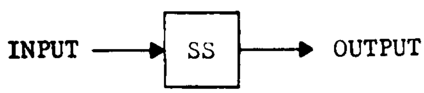

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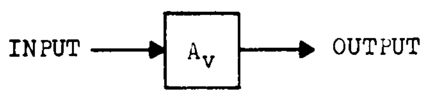

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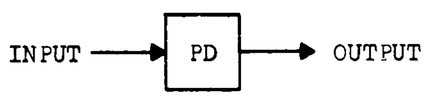

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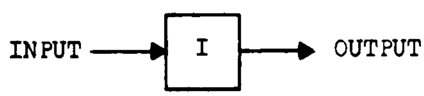
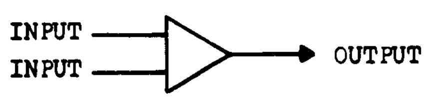
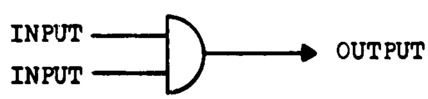


INVERTER

DELAY CIRCUIT



AND GATE FOR NEGATIVE SIGNALS



OR GATE FOR NEGATIVE SIGNALS

1.0 INTRODUCTION

1.1 THE MODEL X-1 PRINT READER

Several years ago, active work was begun on a laboratory model print reading machine termed the Link Model X-1. This was a single line numeric reader and became operational with a vocabulary of 10 digits. The reader was subdivided into the three basic units which characterize any commercial print reading equipment — Data Pickup Unit, Recognition Unit, and Output Unit.

The Model X-1 was constructed to provide proof of feasibility of the basic Link reading technique. This reader was simple, yet unique in design and its performance characteristics strongly supported the technique. The salient features of the Model X-1 reader are listed below:

1) Horizontal Registry - complete independence of horizontal character position achieved. This means that both fixed and proportional character spacing is handled with equal ease, the only restriction being that a finite, vertical, white swath was necessary between characters.

2) Vertical Registry - a compensation scheme involving the use of additional photosensors above and below those which view the characters in nominal vertical registration proved to be feasible. However, the number of sensors used did not provide adequate scanning resolution for reliable reading of a large vocabulary over a wide range of vertical registry. (This condition, thereafter, was corrected in the Model X-2 and Model X-3 Readers.)

1.2 THE MODEL X-2 PRINT READER

The results of the Model X-1 development provided Link with sufficient encouragement to proceed with an expanded and more refined print reader which was termed the Model X-2. This was also a single line reader, having a vocabulary of 12 characters plus space sensing capability in any of three different type styles (Prestige Pica, Artisan 10, and IBM 407).

Figure 1-1 is a photograph of the Model X-2 Print Reader and Figure 1-2 identifies the various sub-units within the photograph. The scanning mechanism shown had been designed by Link purely for the recognition system development and has since been replaced by a page feeding and scanning mechanism. Experiments demonstrated that the machine could read the 12-character font reliably at speeds up to 500 characters per second.

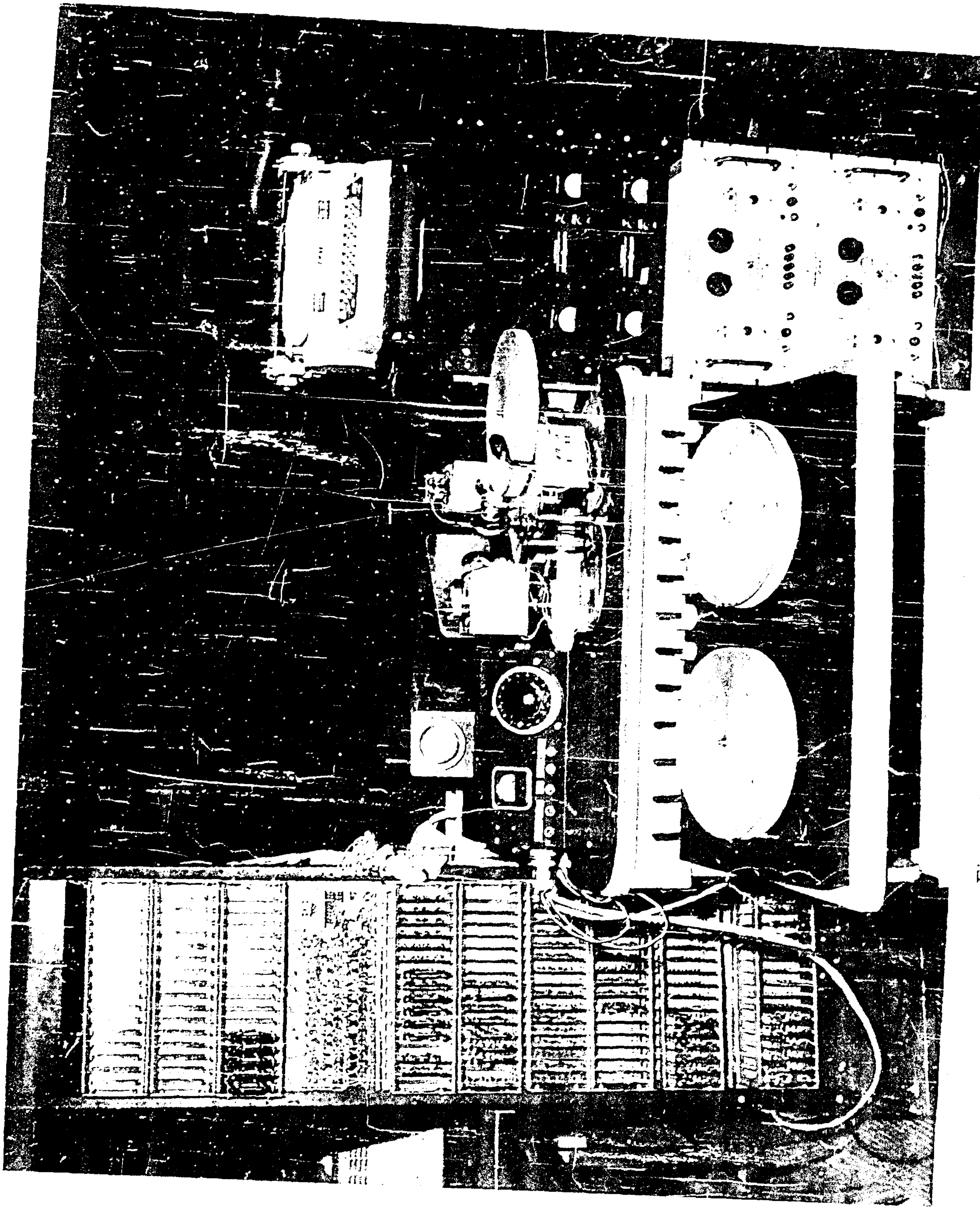


Figure 1-1 MODEL X-2 PRINT READER

1. MEMORY MATRICES
2. MEMORY MATRICES
3. STORAGE & READOUT CIRCUITS
4. TYPEWRITER DRIVERS
5. DECODERS & DRIVERS
6. STORAGE & READOUT CIRCUITS
7. DECODERS & DRIVERS
8. SCAN RING COUNTER
9. READOUT SINGLE-SHOTS & ERROR CHANNEL
10. CLOCK
11. ROW COUNTER
12. VIDEO SCAN COUNTER
13. VIDEO SCAN COUNTER DECODER & DRIVERS
14. CHARACTER GATE DELAY & READOUT SINGLE-SHOTS
15. VIDEO AND & OR GATES
16. CHARACTER GATE
17. PHOTODIODE AMPLIFIERS
18. TERMINAL STRIPS
19. POWER INVERTERS
20. VIDEO AND & OR GATES
21. CHARACTER GATE
22. PHOTODIODE AMPLIFIERS
23. MASTER CONTROL
24. LIGHT SOURCES
25. TURNTABLE
26. OUTPUT TYPEWRITER
27. -10 VDC POWER SUPPLY
28. +10 VDC POWER SUPPLY
29. -28 VDC POWER SUPPLY
30. +28 VDC POWER SUPPLY

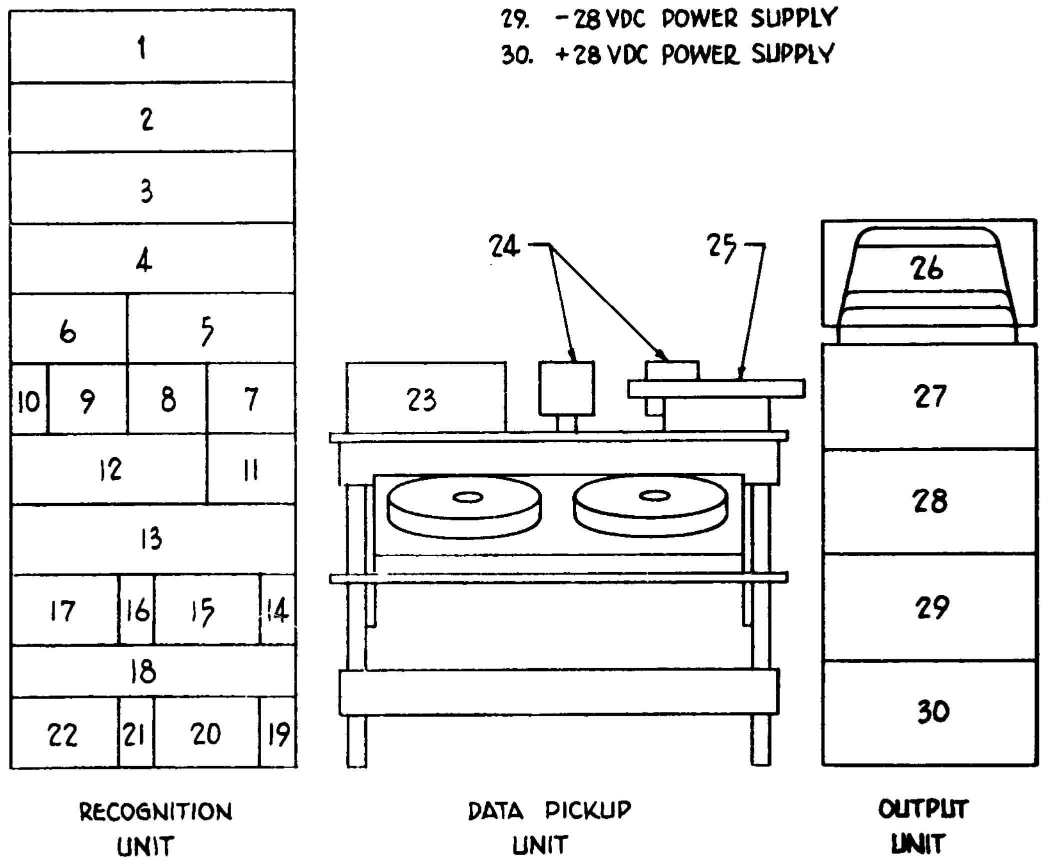


Figure 1-2 MODEL X-2 COMPONENT ARRANGEMENT

2.0 DISCUSSION

The Model X-2 machine provided the basis for Air Force interest in the Link Reading Technique. This interest resulted in the award of contract AF 30(602)-2642 for study and experimentation leading toward the design of a Universal Print Reader. An expanded and more refined laboratory reader developed privately by Link was made available for use in the Air Force study contract. This machine, being a logical continuation of earlier development efforts, was designated the Model X-3 (Figure 2-1) and was the principal hardware used in conducting the studies required under the Air Force contract.

2.1 THE DATA-PICKUP UNIT

The Data-Pickup Unit, Figure 2-2, includes the means for feeding documents, scanning the characters to be identified, and for discharging documents in an orderly fashion after they are read.

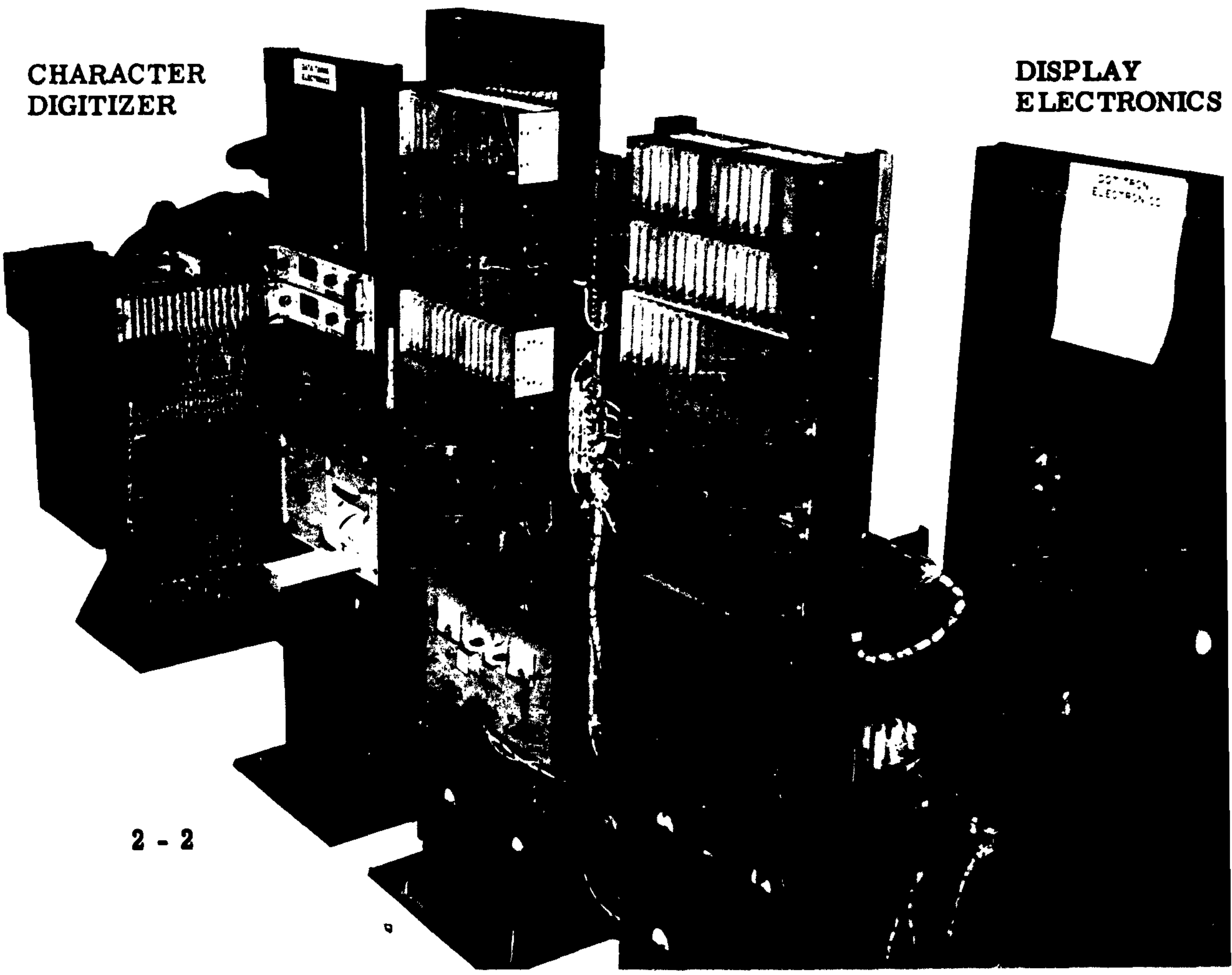
After carefully considering many commercially available document handling mechanisms, Link had decided that in order to fulfill general scanning requirements, it would be necessary to design and build a complete unit specifically for optical scanning. In the following paragraphs, a detailed description is given of the various mechanisms which make up the Data-Pickup Unit.

2.1.1 Document Feeding

A Universal Print Reader must be capable of handling documents which vary in both size and weight, without jamming or double feeding, and without extensive manual adjustment. In addition, documents must be handled which have been subjected to field usage and, therefore, a reasonable number of tears, wrinkles and folds must be expected.

Initially, a commercially available feed mechanism had been purchased by Link and evaluated for print reader application. This was the feeder portion (including base) of an Addressograph-Multigraph Model 1250W Offset Press and is shown installed during one stage of development of the Data-Pickup Unit (Figure 2-3). This feeder will handle nine to 20 pound bond paper ranging in size from 3-inch by 5-inch to 11-inch by 17-inch, however, it can tolerate very little document degradation due to field handling. Testing of this unit also indicated that varying document sizes cannot be fed from a flat position reliably on an intermixed basis since shorter sheets must be moved so as to bring all leading edges in common alignment.

Figure 2-1 MODEL X-3 PAGE READING SYSTEM



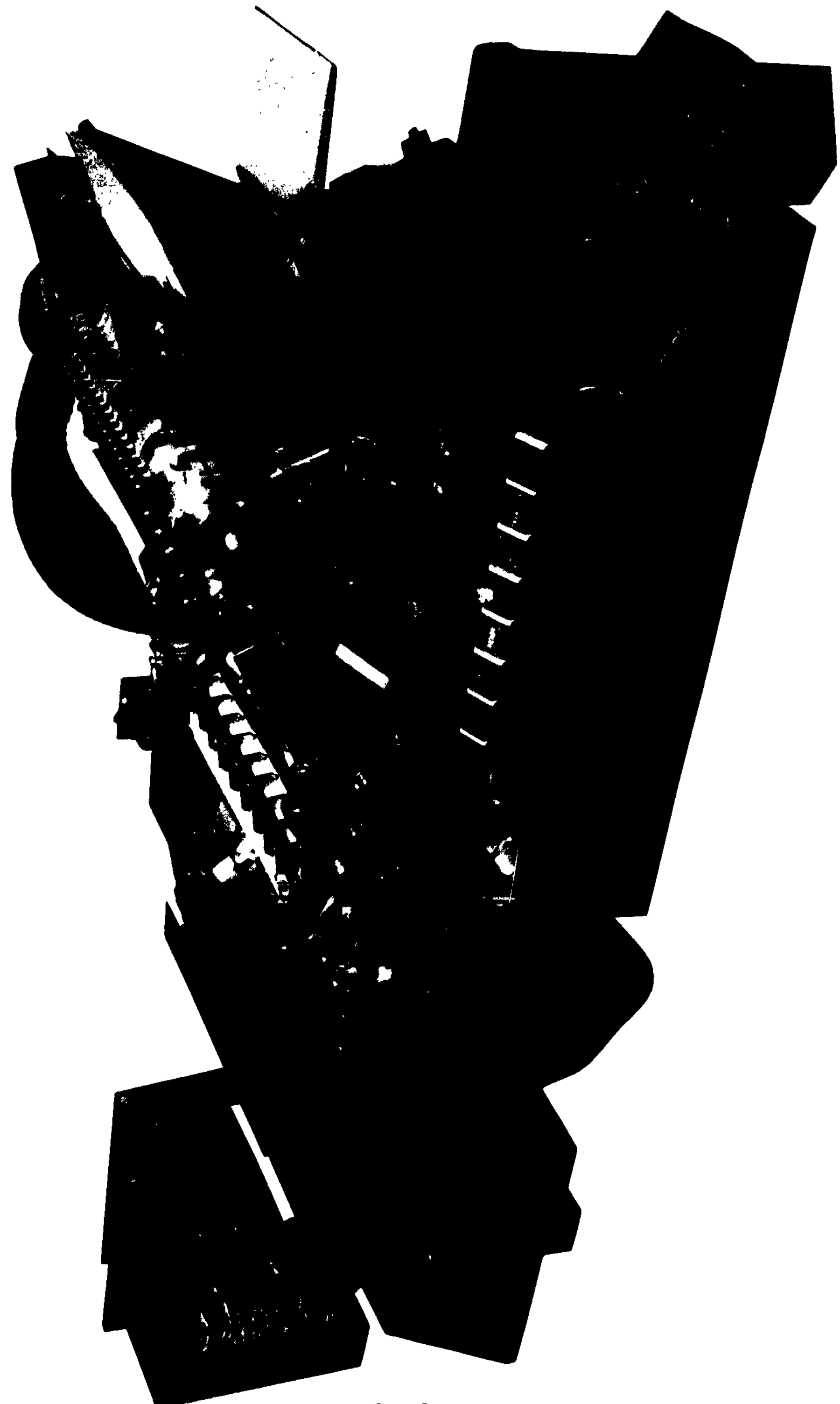


Figure 2-2 MODEL X-3 DATA-PICKUP UNIT

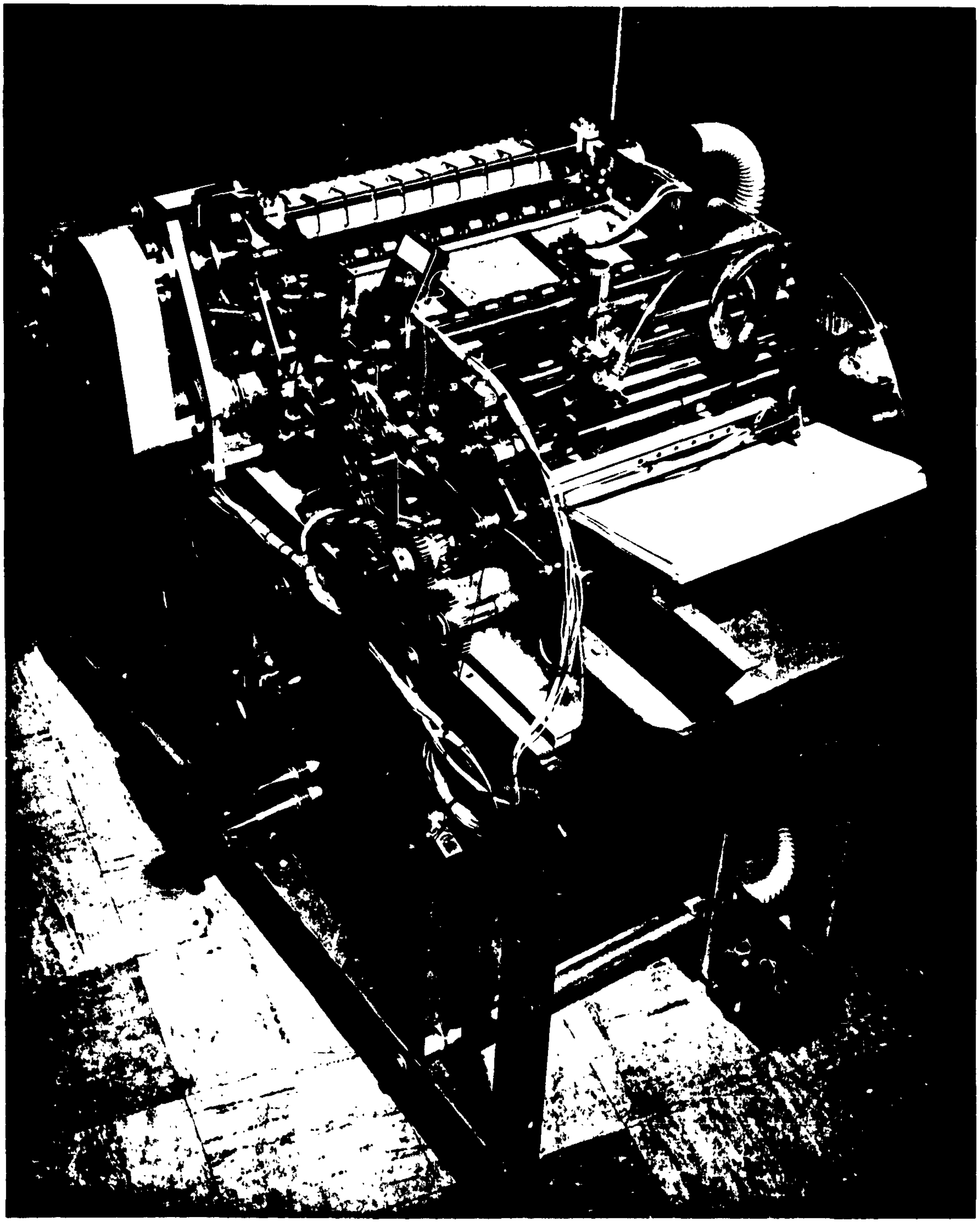


Figure 2-3 COMMERCIAL FEEDER EVALUATION MODEL

Since a more universal type of feeder was required for optical scanning purposes, a completely new mechanism was developed having greater versatility. In this new configuration,documents are loaded and fed from an inclined position. As with the Multilith Feeder, the top sheet is picked up by vacuum and sheet separation is aided by fluttering the document edges with air pressure, however, additional vacuum ports and an oscillating mechanical motion to achieve pickup action is incorporated. The vacuum ports can be individually deactivated to accommodate smaller document sizes.

2.1.2 Document Scanning

The feed mechanism supplies documents individually and sequentially for loading onto a rotating cylinder called the Document Drum. The documents are prepared for loading such that the lines of character data are normal to the axis of the drum. In this manner,the characters are sequentially viewed by the projection system while each line can be scanned by successively positioning the optical projection system carriage over each line to be read.

Documents arrive on demand from the feed mechanism to a loading gate as shown in Figure 2-4. At the proper interval of the document drum cycle, the loading gate opens and the document is accelerated onto the drum by rollers. Because of the speed differential between paper and drum,the document is driven under a series of spring-tensioned mechanical fingers which align and grip its leading edge. As the drum rotates further, the document is pulled onto the cylinder and held in intimate contact by vacuum ports. Figures 2-5A and 2-5B are simplified cross sections of the document drum showing the gripper finger mechanism in its open and closed positions. Figure 2-6 is a photograph showing the Feed and Document Drum Scanning Mechanisms.

2.1.3 Document Discharge

After reading the final data on a document, the gripper fingers release the leading edge and another set of mechanical fingers are moved into a series of grooves cut circumferentially into the surface of the Document Drum. The document is, therefore, stripped from the drum and guided to the output hopper as shown in Figure 2-4.

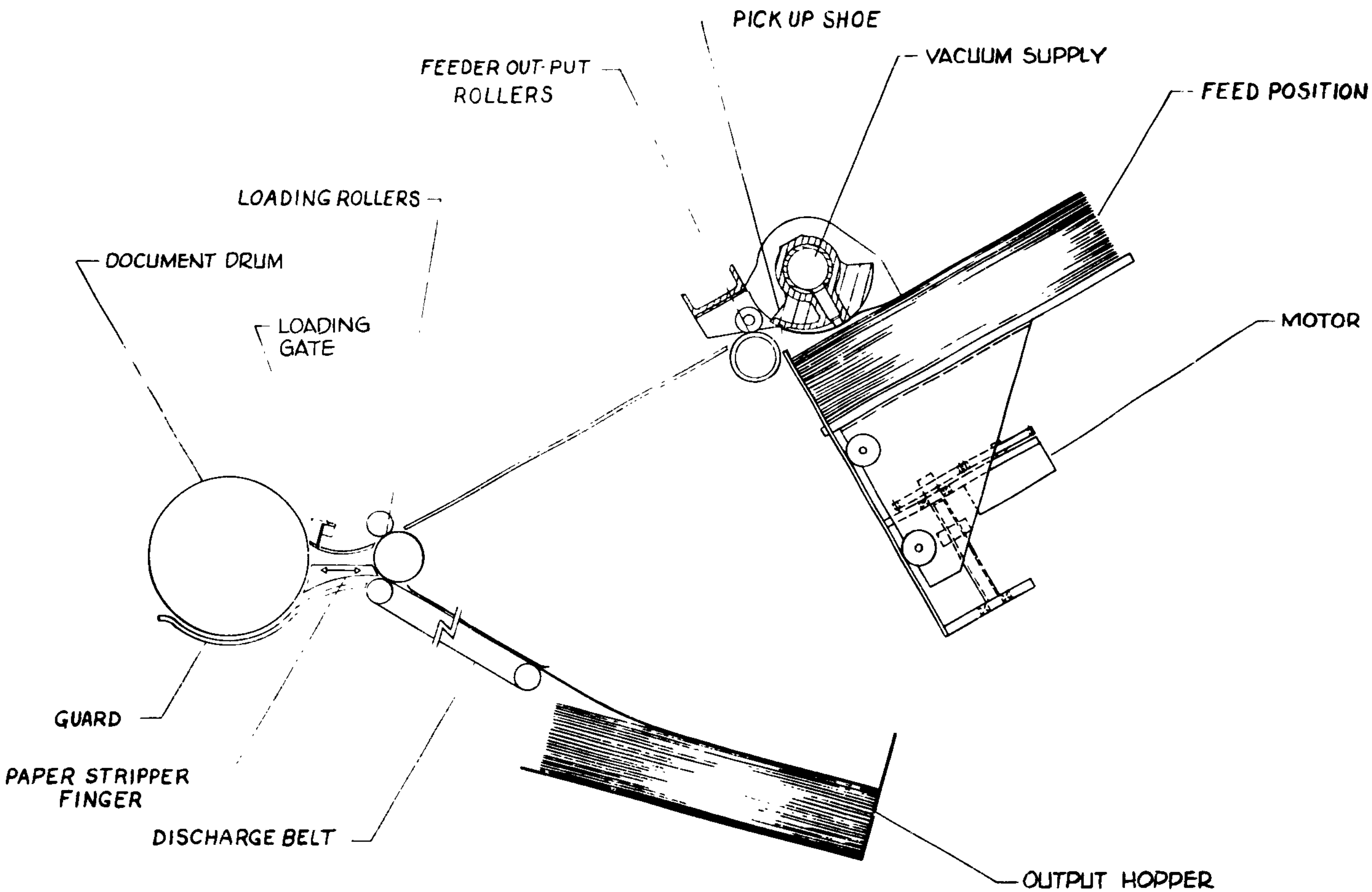


Figure 2-4 SECTION ALONG DOCUMENT PATH

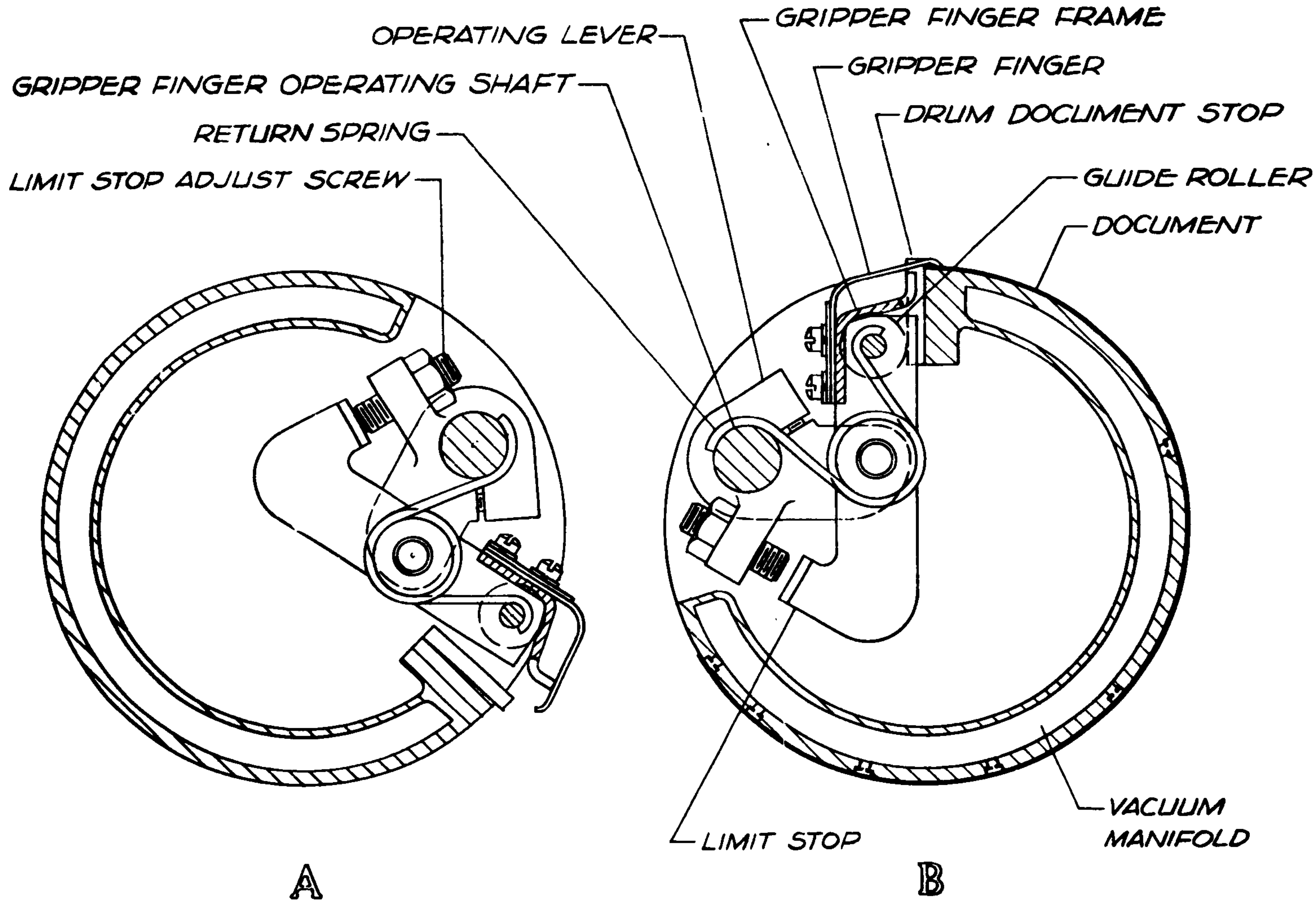


Figure 2-5 CROSS SECTION READ DRUM

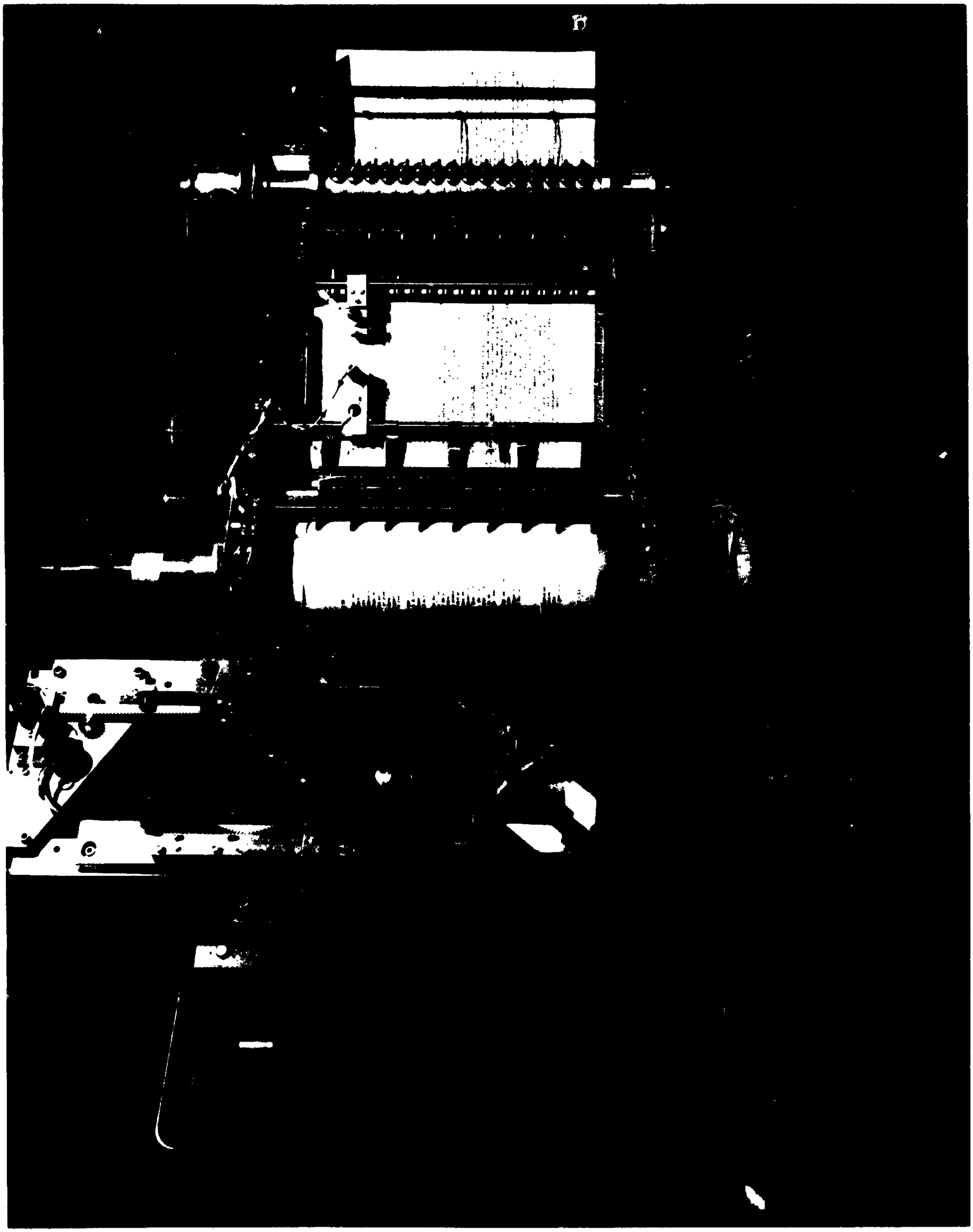


Figure 2-6 FEED AND DOCUMENT DRUM SCANNING MECHANISMS

2.1.4 Line Finding

The Model X-3 Print Reader uses a line finding system which performs the function of locating the first line on the document to be read. This is necessary in even the simplest page reading devices due to the tolerances of form printing coupled with the normal variation in first line placement by typists. The carriage-mounted dual element photosensor locks onto the first line during the first revolution of the document drum and establishes a reference carriage position from which subsequent carriage advances are made. Carriage advance takes place only during the interval between the trailing and leading edge of the document being scanned and is, therefore, stationary during the time that reading takes place.

A simplified block diagram of the line finding system is shown in Figure 2-7. Fixed increments of carriage advance are provided, therefore, documents must be prepared with fixed line spacing (single or double). Due to the vertical registration tolerance of the Recognition Unit, however, it is not necessary that line spacing be precise or that the optics carriage be positioned perfectly over each line.

Referring to Figure 2-8, the light sensor and a four element 1:1 projection lens is mounted on the optics carriage positioned at a fixed distance from the reading lens L_1. The complete line finding optical system consists of lens L_2, mirror M_4 and the differential dual photocell. This photocell consists of two independent photovoltaic elements deposited onto a common base. The sensor is positioned such that the division between the two rectangular elements is parallel to the line being sensed.

The size of the cell is such that several adjacent characters of a line will be projected onto its surface. This has an integrating effect and averages the light from approximately eight adjacent characters such that spaces between characters and between words are ignored. If both portions of the sensor are equally illuminated, the output signal from the differential amplifier is zero. This is the case if either no line is projected onto its surface or if the line is precisely centered. If, however, the sensor head is not centered above the line, the image of the line will move onto one or the other of the elements resulting in an output from the sensor and a corresponding output from the amplifier. The closed-loop servo system will then move the carriage until the line image is centered on the light sensor. Figure 2-9 shows the resulting error signal due to relative displacement between line and carriage.

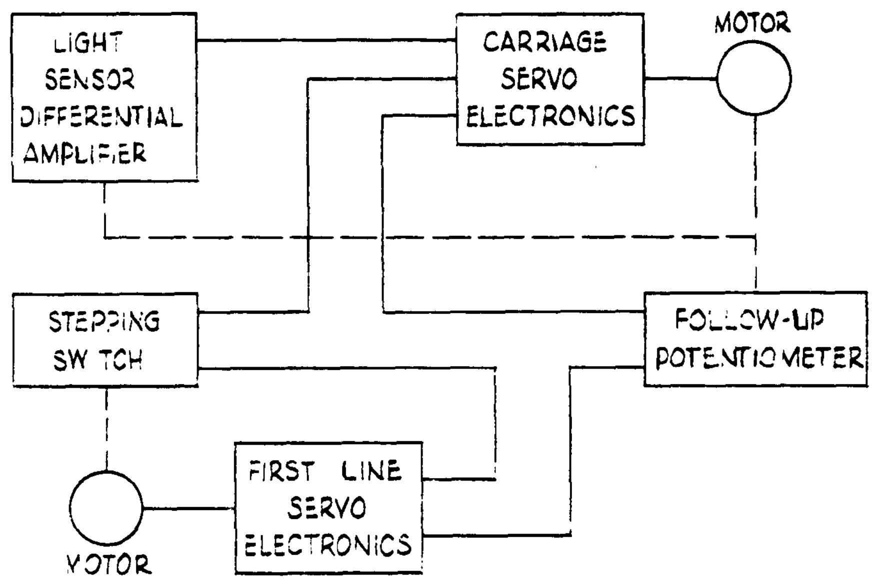


Figure 2-7 LINE FINDING SYSTEM BLOCK DIAGRAM

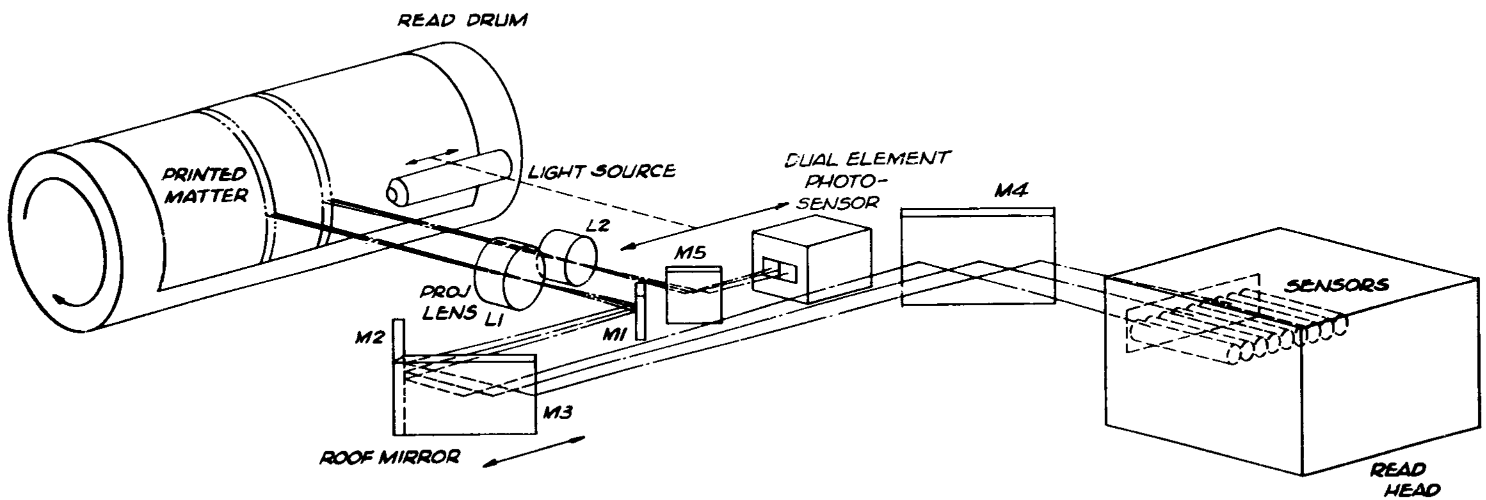


Figure 2-8 OPTICAL SYSTEM CONFIGURATION

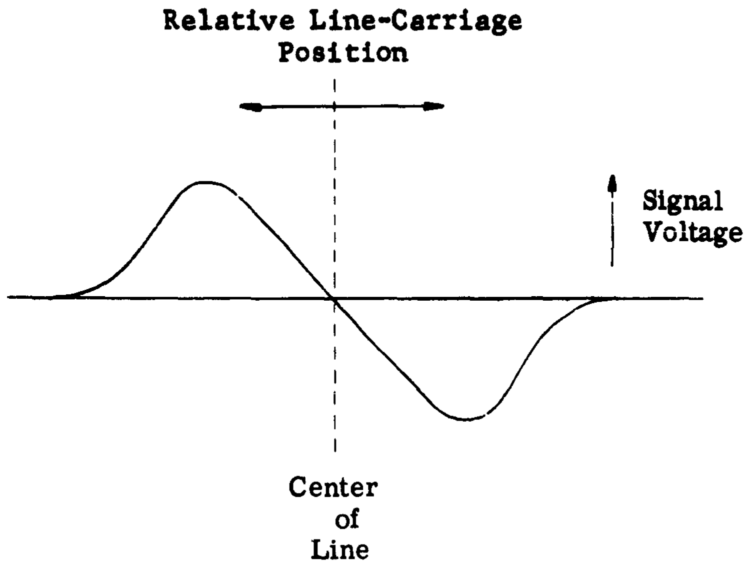


Figure 2-9 LIGHT SENSOR ERROR SIGNAL

2.1.5 Optical System

2.1.5.1 Projection System for Reading Head

For preparation of appropriate input signals to the electronic system of the print reading machine, the spatial information contained in the printed characters is transferred into time sequential information by image dissection in the electro-optical scanner system. The receiver for the dissector portion of the print reader (Figure 2-10) consists of two rows of photosensitive elements. Consequently, an optical projection system is used for the transfer of information.

Basic requirements for the projection system are dictated by the configuration of the reading drum, physical size of the printed characters, size and resolution of the photodiodes which are used as photosensitive elements in the reading column, and their sensitivity to light.

The document is read line by line. With a rotating cylinder providing the line scanning motion, the reading head performs a stepping

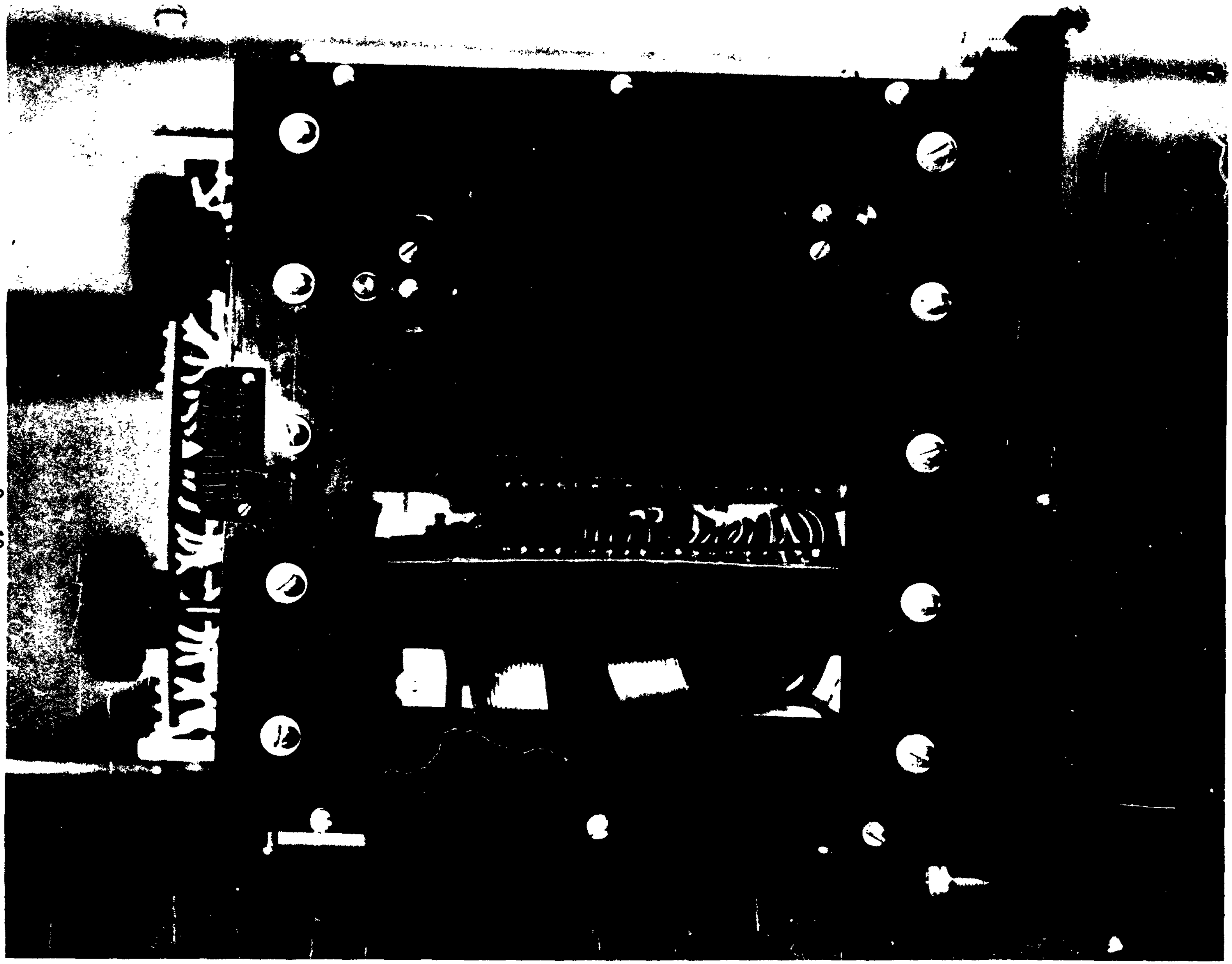


Figure 2-10 PHOTODIODE ARRAY IMAGE TRANSDUCER

motion parallel to the axis of rotation in increments equal to the line spacing. The configuration of the optical train is such that this is accomplished without the necessity of moving the photodiode column which would be impractical considering the large number of cable connections to the Recognition Unit.

The system, shown in Figures 2-8 and 2-11, consists of three different assemblies. The first assembly contains the lens L_1 and one mirror, M_1, mounted on the lens carriage. This carriage rides on parallel ways and performs the incremental motion from line to line along the document, under control of the line sensing and advance system. The second subassembly, consisting of two mirrors, M_2 and M_3, is mounted on a mirror carriage. The mirror carriage rides on the same guide ways and is mechanically connected by a rack and pinion arrangement to the lens carriage, so that it traverses half the distance of the lens carriage. This permits the third subassembly, containing another mirror, M_4, and a row of photodiodes, to be mounted stationary at the image plane, and keeps the optical distance constant independent of the position of the line being scanned. The projection distance (object-image distance) is determined by the physical size of the document and reading drum and is approximately 25 inches.

The projection distance and the required magnification determined the focal length of the projection lens. The magnification is derived from the resolution of the image dissector.

Sufficient information for recognizing the character can be extracted from 25 vertical resolution lines. Consequently, the character must be projected at such a magnification that its image covers 25 photodiodes. Because of the physical size of the photodiodes (0.082 inch diameter), the character has to be scaled up to 2.05 inches. For most normal ten pitch type styles a magnification of 17.75X is required.

The only special requirement for the projection lens is a long back focus for avoiding interference with the illumination system. This lens (L_1 in Figure 2-8) is an inverted telephoto design, which shortens the focal length and increases the working distance. Effective focal length of this five element projection lens is 29mm.

It should be noted that in the horizontal direction (along the lines), the magnification could be reduced, since the number of vertical scans across the character is less than the number of horizontal resolution elements (photodiodes). From illumination considerations, an anamorphic projection system, which would provide the required minimum

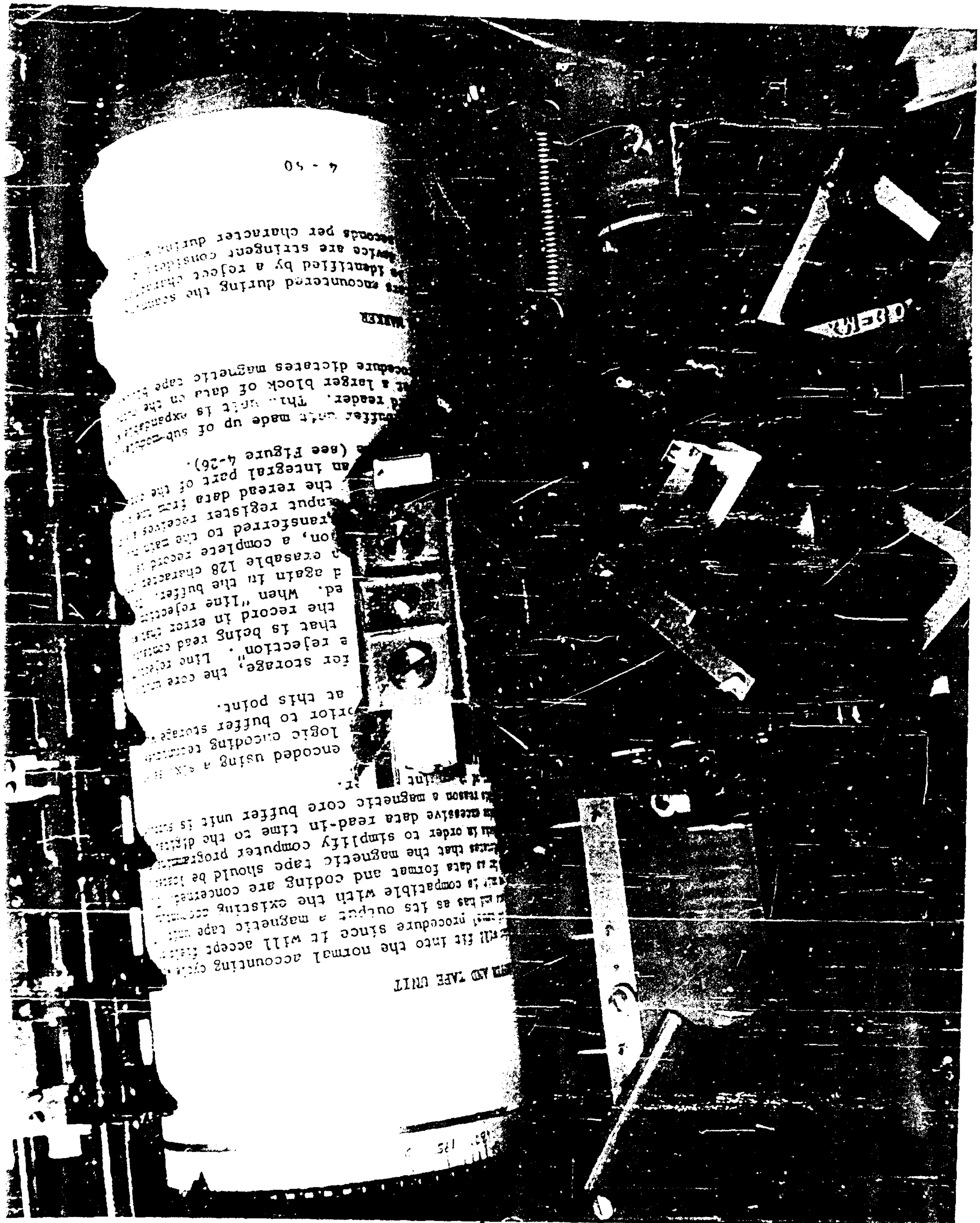


Figure 2-11 DOCUMENT DRUM AND CARRIAGE-MOUNTED ILLUMINATION AND PROJECTION SYSTEM

magnification in both the horizontal and vertical directions offers an advantage, since the reduction of image brightness is proportional to the product of horizontal and vertical magnification. An anamorphic projection system could be designed which would reduce the illumination requirements. However, since the required image brightness can be obtained with the spherical projection lens and light source presently being used, no attempt was made to use a special (and costly) anamorphic design.

2.1.5.2 Illumination System

Illumination of the document surface must be provided to achieve the necessary brightness of the image at the sensors of the reading column. In addition to intensity, constant illumination over the whole field, and proper positioning of the light source for eliminating glare and improving contrast are required.

The system uses a quartz-iodine light source mounted in a cylindrical ellipsoid reflector. The coiled filament is positioned in one focal line of the ellipsoid, which is mounted at 45 degrees to the document surface, such that the other focal line coincides with the object plane. Since the reflector is cylindrical, the filament is imaged onto the paper surface only in one dimension which does not produce an actual image, but produces instead, a structureless linear concentration of light at the position of the character to be read.

The lamp is rated at 625 watts, 115 volts, but is used at reduced voltage (65 volts) where it dissipates 260 watts and provides the required brightness of 50,000 foot-lamberts at the document surface. At this low voltage, the life of the light source is increased theoretically by a factor of 5,000. The mechanical vibrations during carriage return may reduce this factor somewhat, but up to the present time, no failures have occurred so that an accurate prediction of lamp life cannot be given. A second advantage of operating the lamp at reduced voltage is that the maximum spectral emissivity shifts to longer wavelengths. This provides a better match between the spectral characteristics of photocells and light source since the spectral sensitivity of the photodiodes has its maximum around 800 mμ (short infrared).

2.1.6 Data-Pickup Unit Control System

Synchronized feeding, loading and unloading of documents is essential for a reliable optical scanning device. A control system is

required, therefore, to provide correct timing. In the Model X-3, mechanical timing is provided by cams while cam-operated micro-switches and photoelectric controls synchronize electrical events. Magnetic clutches and brakes are the primary controlling means for the feeding and drum loading operations.

The Data-Pickup Control System has two modes of operation, single sheet feed and the automatic or continuous feed. The single sheet mode is used for continuous scanning of a single document with the document change cycle initiated by manual control. The automatic mode provides continuous document reading and evaluation of document handling characteristics. A block diagram of the Control System is shown in Figure 2-12. Figure 2-13 is a timing chart showing the sequence of events during a document change cycle.

2.1.7 Future Improvements

2.1.7.1 Reject Marking

It is highly desirable for a reading machine to visually identify on the original documents those individual characters which it can not read. The requirements for such a marking system are rather severe: it should operate at very high speed (in the order of 500 marks per second), be able to mark common bond paper and require minimum maintenance. Also, for compatibility with the Model X-3 Data-Pickup Unit, the marking device should be as small and lightweight as possible so as not to adversely affect the operation of the servo-driven carriage mechanism on which the marker must be mounted. Although this seems like a difficult set of specifications to meet, a reject marking system has been partially developed which has, at least potentially, all the above advantages.

Several basic marking systems were investigated prior to pursuing the development of a particular method. One possibility would be to produce an electrical arc discharge in close proximity to the document using an electrode material which would leave a "smokey" deposit on the paper. This approach was abandoned. One reason is that such an electrode material (copper for instance) erodes rapidly with successive arcing. Therefore, a means must be provided for replenishing the electrodes automatically while, at the same time, maintaining proper electrode spacing across which to draw the arc. Such a mechanism would be complex, expensive, and probably unreliable. An electrode material which does not erode rapidly, does not leave a "smokey" deposit (silver or platinum for instance) and produces no clearly visible mark as a result of an arc discharge unless

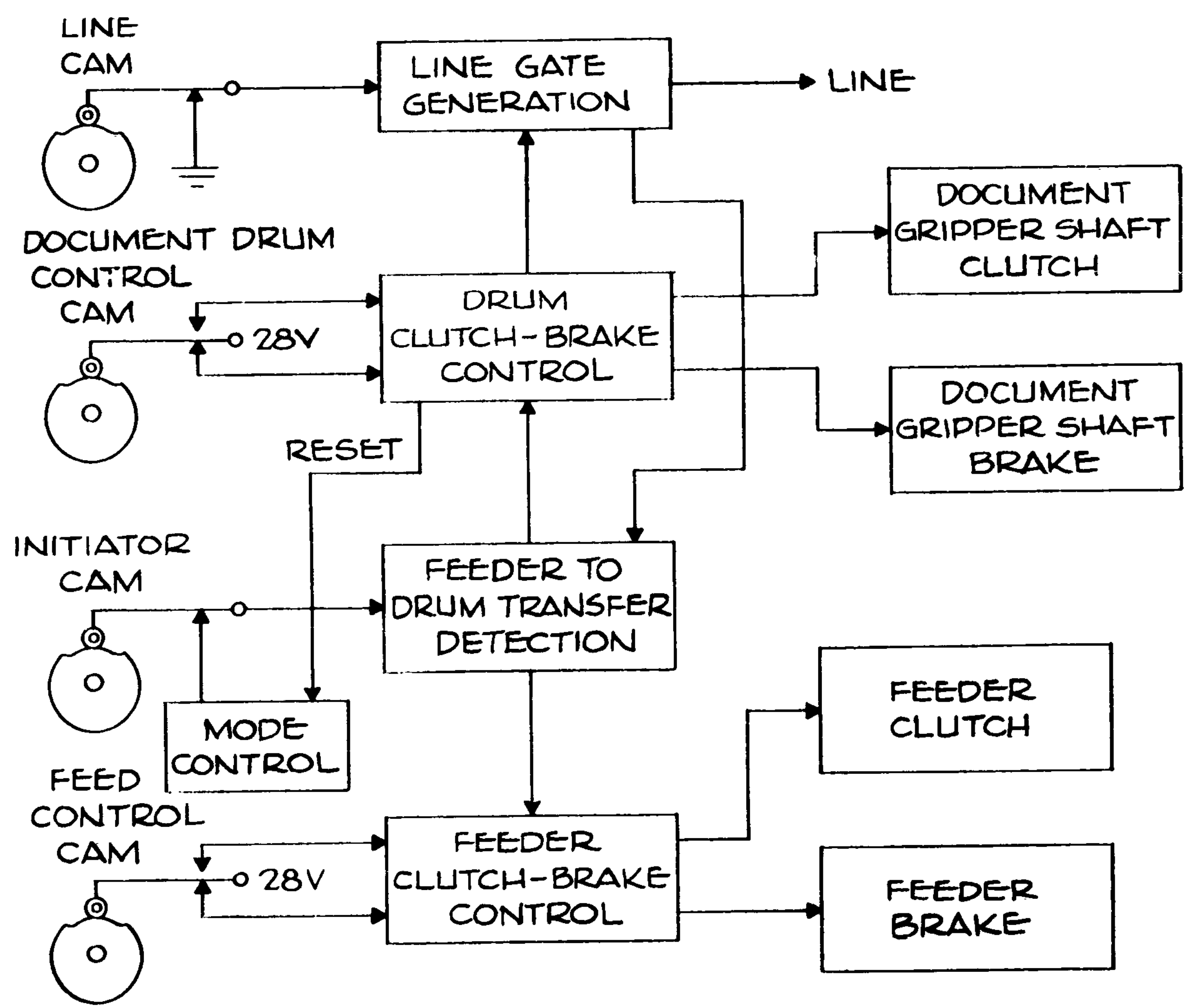


Figure 2-12 DATA PICKUP UNIT CONTROL SYSTEM

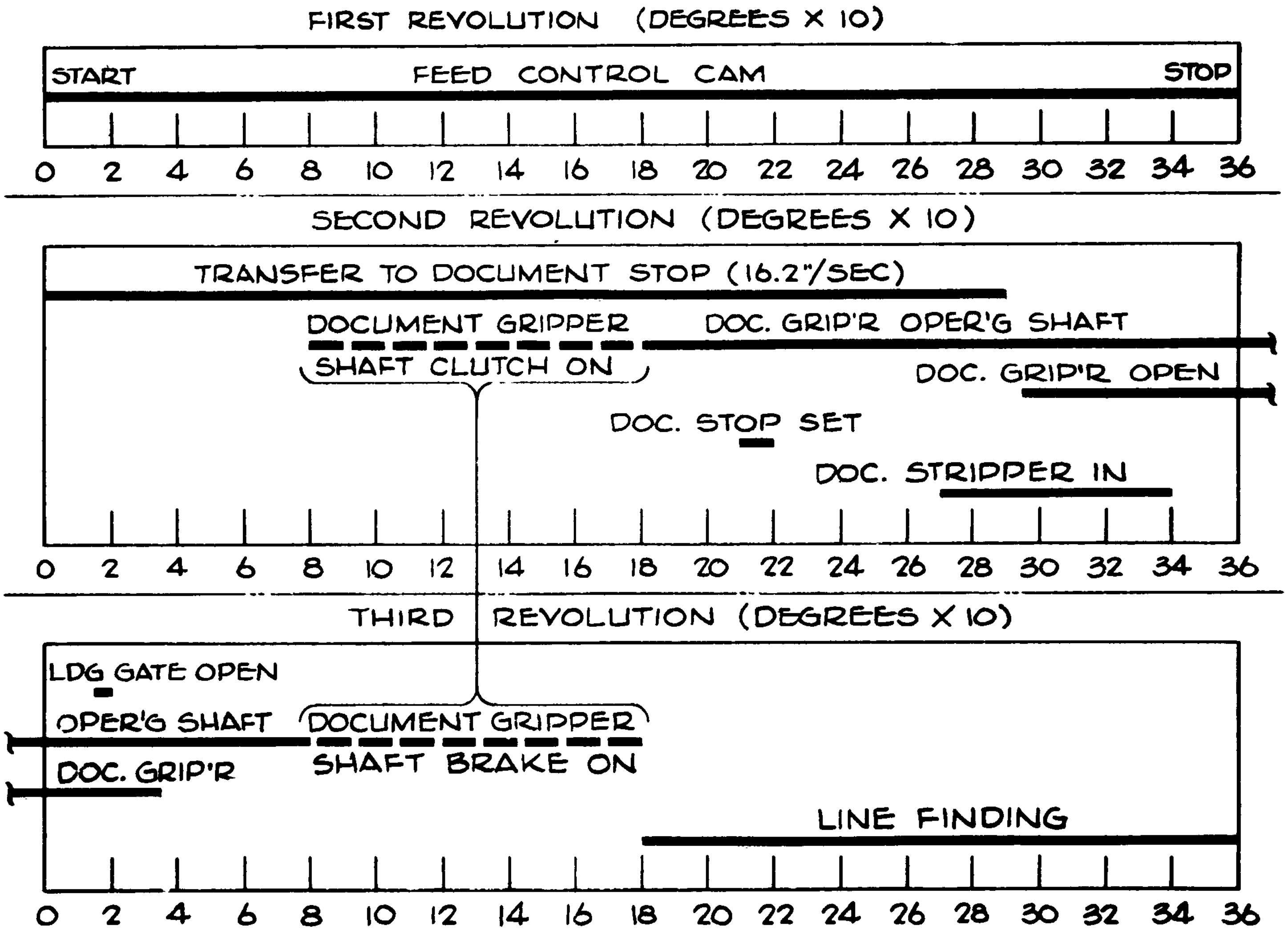


Figure 2-13 DOCUMENT CHANGE CYCLE TIMING CHART

the paper fibers of the document are heated to the point of ignition. This is, of course, undesirable from the standpoint of safety. The inherent requirement for high voltage supplied to an arc discharge device on the carriage mechanism is unattractive also when operator safety is considered.

A second system considered was the use of a xerography technique in which the document rotates in contact with a selenium drum having powder deposits in the vicinity of each rejected character. The selenium drum must be scanned in synchronism with the Model X-3 document drum and be exposed to a spot of light at the occurrence of each reject. A colored powder is then sprayed over the drum adhering only to the spots exposed to light. The document is then rolled in contact with the drum picking up powder deposits in all positions corresponding to the rejected characters. This system is presently used in xerographic printing processes and has the advantage of extremely high operating speed (up to 10,000 marks per second) and would not require additional components on the present optics carriage. However, it does require an additional synchronously operating drum and carriage system. Due to the high complexity and cost of this system, it was not pursued further.

A marking technique which appears most desirable when considering complexity, reliability, and cost utilizes an electro-mechanically operated pen mechanism. These devices are already in common usage as event markers on certain types of chart recording instruments, however, all appear to be limited in operating speed to about 150 cycles per second. After testing a device of this type shown in Figure 2-14, it was found that the speed could be raised to 200 cycles per second by applying an overvoltage to the actuating coil and replacing the armature return spring with one having a higher spring constant. Overvoltage on the coil does not cause malfunction if the duty cycle is restricted. (This can be done in the Reader by logically specifying a limited number of successive rejects permitted before rejecting the entire document.)

An additional speed increase might be obtained by overdriving the solenoid coil by several hundred volts for only a very short initial portion of the energizing pulse, then disconnecting it before overheating can occur. This can be accomplished electronically using high voltage power transistors or gate turn-off silicon controlled rectifiers as the driving elements for the solenoid coil.

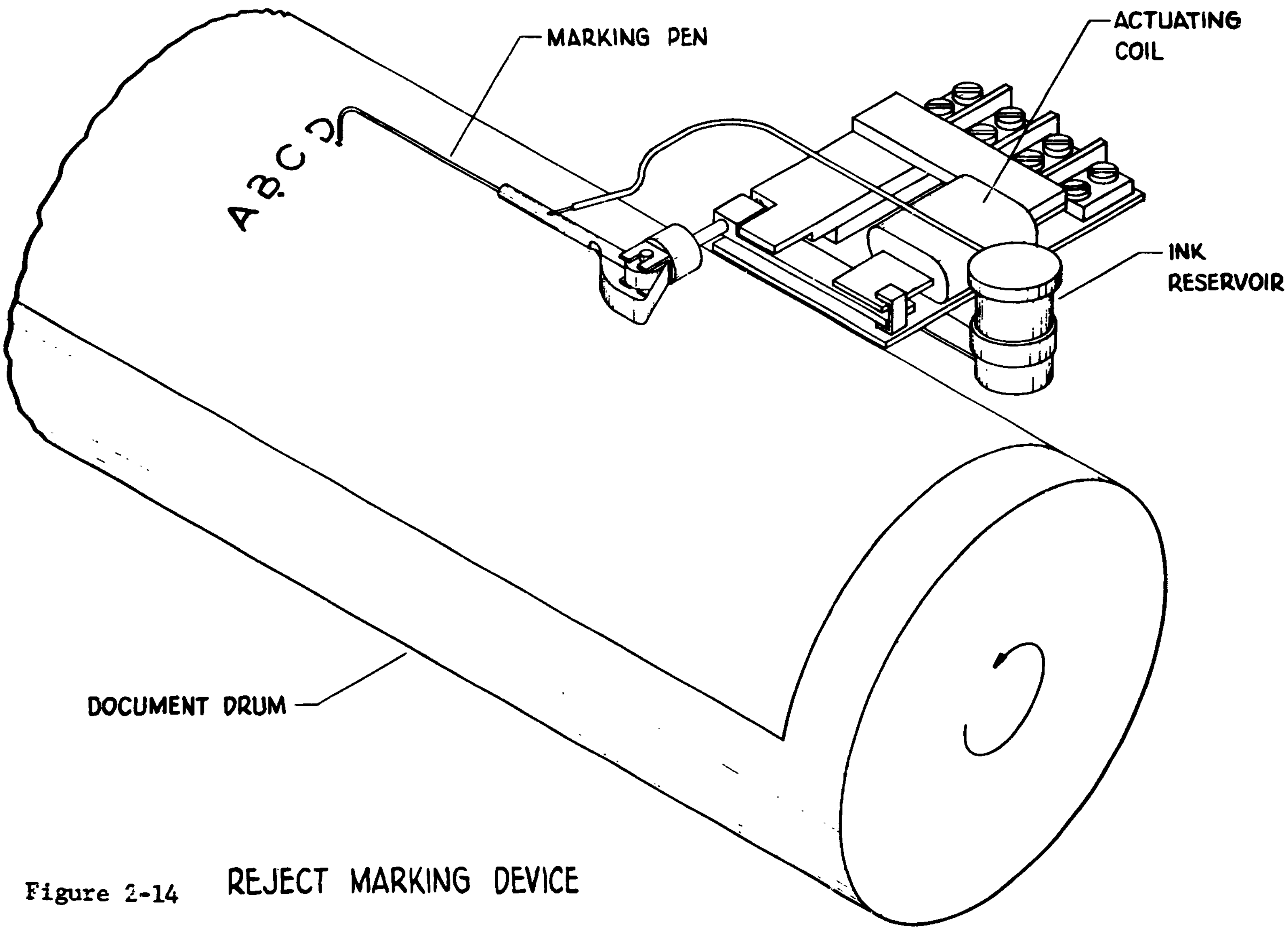


Figure 2-14 REJECT MARKING DEVICE

2.1.7.2 Employment of Fiber Optics

The physical size of the reading head is responsible for the present configuration with stationary photodiodes and optical mirror carriage (see Section 2.1.5.1). If the photosensors could be made to a size of only 1/25 of the character height, a very small and compact system would result in which photosensors and 1:1 imaging optics would be mounted on the line carriage and the mirror trombone eliminated.

As a means of reducing the apparent size of the photodiodes, the possibility of using glass fibers has been investigated. The basic concept of a glass fiber photodiode reading head would be as follows: Clad glass fibers of a diameter equal to the actual size of a minimum resolution element (0.04 inches) are mounted in two rows at the image plane of a unity magnification optical system as the read and pre-read column, respectively. The other end of the individual fibers is cemented onto flat window photodiodes at the position of maximum sensitivity, e.g., where the cone of light leaving the fibers nearly covers the area of the photojunction.

The use of glass fibers also had promise of higher sensitivity,if the cone of light acceptance of the fibers would be equal to or larger than the numerical aperture of the optical system. In addition, this technique may have made it possible to reduce the wide sensitivity spread of the diodes because of the feature of accurately cementing the fibers onto the diodes at the position of maximum sensitivity. The actual size of the reading head would then be reduced, since the glass fibers are flexible and the photodiodes could be mounted in a cluster rather than in a column as the present concept.

The numerical aperture of a fiber is equal to

$$NA = \sqrt{n_1^2 - n_2^2}$$

where n_1 = refractive index of core

n_2 = refractive index of cladding

The NA of most fibers is equivalent to a relative aperture of F/1.5 or better, so that there is no light attenuation due to aperture restriction. Because of imperfections in the fiber surface, however,

the attenuation of short fibers generally exceeds 50 per cent. This loss could be recovered,if the light transfer from the end of the fiber onto the photojunction would be more efficient than the light transfer on the photodiodes with cemented lens (standard LS400 configuration) used in the conventional system.

In an experiment, the end of an illuminated glass fiber was moved around the surface of a flat face photodiode, (LS500) by means of a micropositioner. The output signal from the photodiode was measured as a function of the position. Figure 2-15 shows the result of these measurements. Isophotes (lines of constant light sensitivity) are shown superimposed onto the sensitive wafer in the photodiode. Actual dimensions are also given in this figure. Imersion oil, or optical cement between window and glass fiber increased the signal about 10 per cent, due to elimination of one reflecting surface.

In continuation of these tests, 100 glass fiber-photodiode combinations were made. The fibers were cemented with Epoxy resin onto the photodiodes in the position of maximum sensitivity. However, the results of this work were not very encouraging. First, the sensitivity spread of the diodes was as high as in the case of the LS400. Second, the glass fiber combination was found to exhibit lower over-all light efficiency than the straightforward projection system - LS400 combination. One last consideration is the fragility of the fiber-photodiode combination. Even with the exercising of extreme care five per cent of combinations fractured at the fiber-cement junction.

The use of this method has been abandoned for the present since it would require higher brightness of illumination on the document surface. At a future date, when photodiodes with higher light sensitivity may be available, the instrumentation of this system may be feasible.

2.1.7.3 Size Normalization

In order to present the printed characters to the reading head at a normalized size, the optical projection system should allow for convenient changes of magnification. The range of optical magnification must be such that characters of all possible sizes (within reason) can be accommodated. During the course of this study, several variable magnifications systems have been investigated. The smallest popular type style that must be accommodated was considered

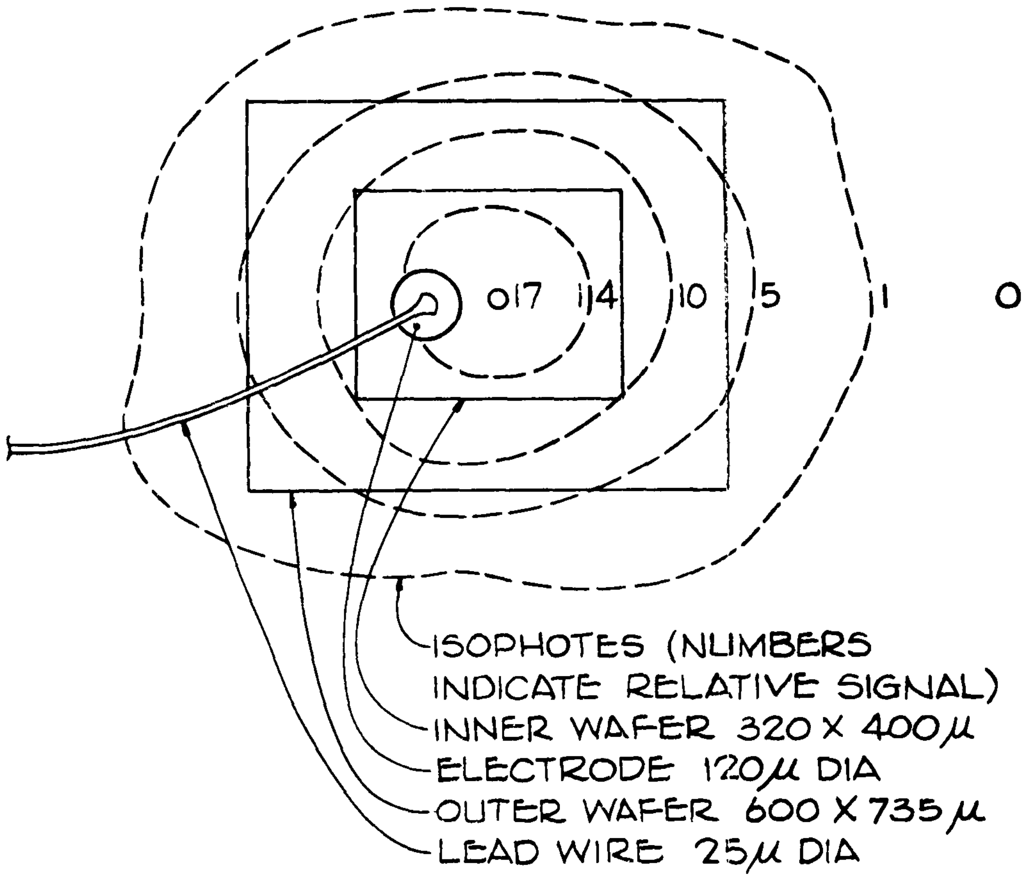


Figure 2-15 GLASS FIBER PHOTODIODE COMBINATION

to be Elite (height 0.095 inches), while the largest character would be 0.125 inches high, such as Modern Gothic. This represents a range of approximately 19 to 25 over which the magnification should be variable.

It should be possible, in a multifont character reader, to change magnification conveniently and quickly. As an ultimate goal, instantaneous automatic magnification change is required whenever a different size character appears on the reading diodes. (This is generally true except in those cases when size is a significant factor in recognition.) It can be stated, however, that font normalization by optical means is not feasible if the various size characters are intermixed on one line. This is a practical consideration since the magnification change is necessarily accompanied by the mechanical movement of optical elements and hence requires a finite amount of time. The two or three milliseconds available between individual words (one character space) is obviously too short to accomplish the required mechanical motions. If the magnification change is required between lines, or between pages, the implementation of an automatic variable magnification system is certainly practical. The information that a magnification change is required will be initiated by a character size sensor or from a programmer, depending upon the particular case.

There are certain basic requirements for the projection lens in the character reader and these impose restrictions on the free selection of variable magnification optics:

1) Long working distance is required for accommodation of the illumination system.

2) The diameter of the lens mount should be as small as possible (only slightly larger than the lens aperture) such that it does not obscure the cone of illumination and cast shadows onto the document reading area.

3) The projection lens must be able to operate satisfactorily in high ambient temperature since it is subject to radiation from the light source. The use of grease on any other volatile substance on the lens mount is not permitted since it may cause deposits on the lens surface which creates fogging.

Functional aspects, such as necessary continuous or discrete magnification changes, time allotted for the change to a different magnification, etc., also influence the selection of a specific system for character normalization.

During the course of this study, the following systems have been investigated:

1) Discrete magnification changes

   a. Lens turret
   b. Auxiliary lenses
   c. Element substitution

2) Continuous magnification changes

   a. Variation in conjugates
   b. Zoom lenses

      (a) Projection zoom lens
      (b) Afocal zoom attachment

Since brightness of the projected image is a factor in any of the proposed optical designs, the general requirements for the illumination system will be reviewed before a detailed discussion of the individual systems.

Assuming that the numerical aperture will remain almost constant during magnification changes, which will be the case for practically all methods discussed here, the brightness of the projected image will be inversely proportional to the square of the magnification. This is not at all desirable since constant image brightness is required, in order to obtain identical signals from the photodiodes. If only occasional magnification changes are necessary, the brightness of the light source may be changed so that the light flux incident on the photodiodes remains constant. However, for instantaneous magnification changes, it will be necessary to normalize brightness either optically or electrically. Optical methods seem to be easier to instrument, considering the large number of individual photodiodes. In variable magnification systems with a continuous range (zoom), this could be accomplished by means of an iris aperture which is connected to the zoom control in such a way that the image brightness remains constant. For systems with discrete magnification steps, the simplest solution is the addition of neutral density filters for all but the maximum magnification.

<u>Lens Turret</u>

Lens turrets for discrete magnification changes have only been considered briefly. The major disadvantages are that they occupy more space than can be made available on the carriage, and that the masses to be moved do not make fast automatic changes feasible.

Auxiliary Lenses

The use of auxiliary lenses appears to be more attractive. For this configuration, since only a small range of magnification must be covered, simple, single element auxiliary lenses suffice. By the addition of a positive lens, the focal length of the projection lens is shortened and since the reading head remains at constant distance, the magnification is increased. Similarly, a negative auxiliary lens increases focal length and results in smaller magnification. Unfortunately, a mechanical problem exists in that two separate mechanical motions are required to refocus the main lens at each change of magnification.

For this reason, a compound lens attachment, which changes magnification without change in focus is more feasible. Since its magnification is close to unity an attachment of this type is quite simple.

The optical design demands that the elements which make up this unit be separated by some minimum distance. This is easily accommodated by assembling the lens elements in a conventional barrel, however, after mounting these separate units onto a turret, the complete assembly is as bulky as the simple lens turret previously discussed. However, unlike the simple lens turret, the auxiliary lens unit can be mounted remotely rather than in close proximity to the document. In addition to not obscuring the light, this makes possible configurations more compatible with the over-all carriage design.

This method of font normalization deserves consideration for a machine which reads not more than three or four sizes of characters on a non-intermixed basis since, in general, sufficient time is available for magnification change.

Element Substitution

The method of changing the focal length of the projection lens by changing one of its elements is similar to the auxiliary lens system except that it is more flexible and requires less refocussing. In the prototype character reader, this system is being used for manual magnification change. As seen in Figure 2-16, the projection lens is a five element inverted telephoto design, with a negative front element. The principal plane is close to the surface of the rear doublet which results in a relatively long back focal length. The negative front element is interchangeable. Focussing affects

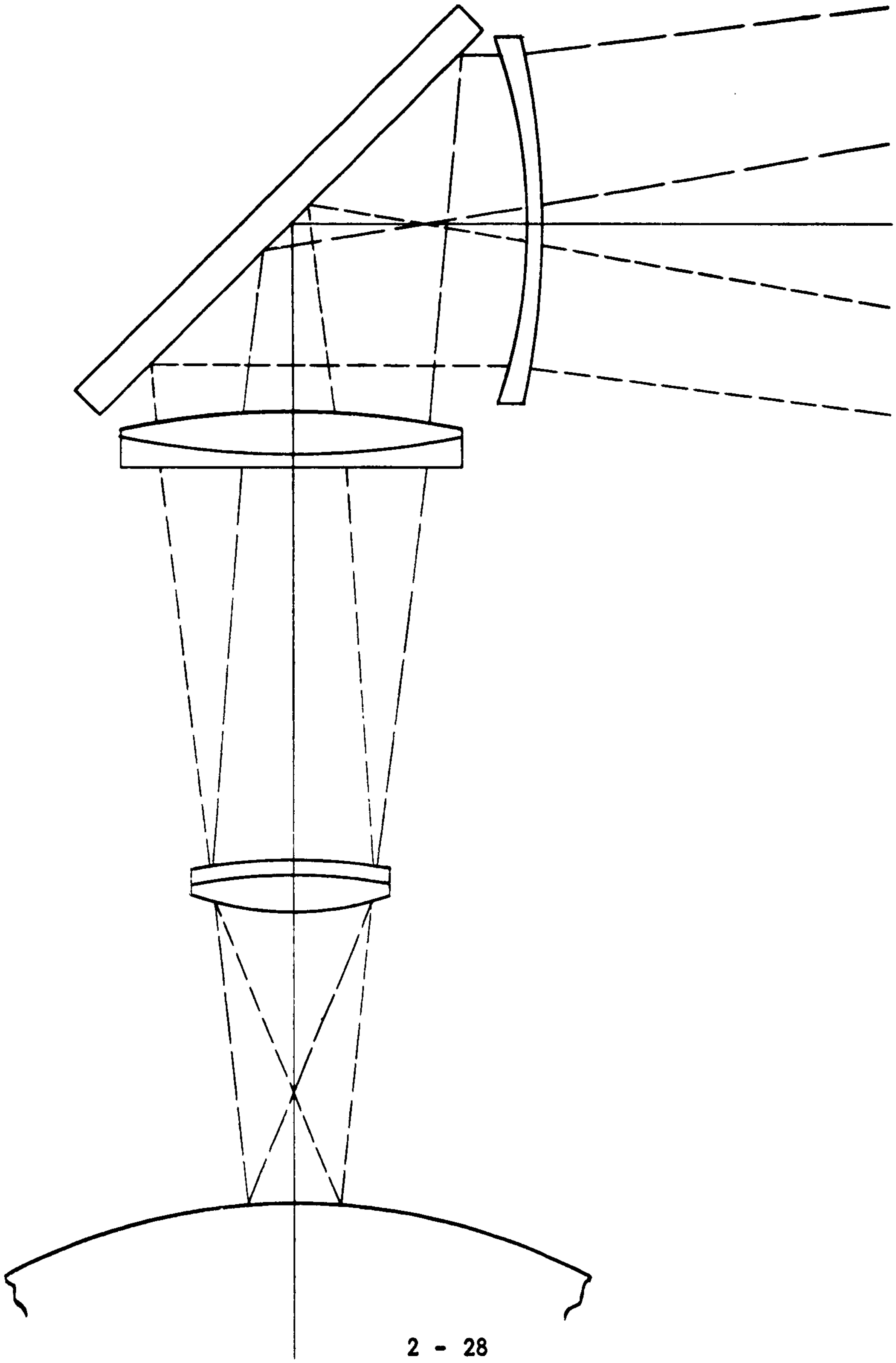


Figure 2-16 PROJECTION OPTICS WITH INTERCHANGEABLE ELEMENT

only the two positive doublets which are mounted in a threaded barrel. Figure 2-17 is a graph showing the relation between negative focal length of the front element and magnification. This system has proven to be quite convenient in the present character reader. However, it does not appear to be practical for automatic font normalization.

Continuous Magnification Changes:

Variation of Conjugates:

This method achieves magnification changes by varying the optical distance between read drum and photodiode column with necessary refocussing after adjustment. The reading head must be mounted on tracks so that it may be moved back and forth without getting off axis. A motion of about six inches would cover the required range of magnification changes for the present character reader. This system can be used for manual adjustments only, adds to the bulk of equipment and was only employed for the first breadboard model (X1) of the Link Character Recognition equipment.

Zoom Lenses

Projection Zoom Lenses

An obvious and apparently simple method presents itself by utilizing a commercially available zoom lens for automatic magnification changes. A survey was made of existing lenses, but none of them was found to be particularly well suited to this application. The most common faults of these lenses are: their unnecessarily large zoom range makes them too large and too heavy for mounting on the lens carriage; they are sensitive to heat radiation; and, due to the complicated mechanism for moving several lens elements, the resulting mounts are large in diameter with a short back focal length such that it would have been impossible to provide shadowless illumination of the reading area. It is certainly feasible to design a zoom lens especially for the intended application, but since this would be too costly for the present program, this possibility was not pursued further.

Afocal Zoom Attachment

The use of an afocal zoom attachment in addition to the regular projection lens also deserves serious consideration for this application. An attachment of this kind is not commercially available,

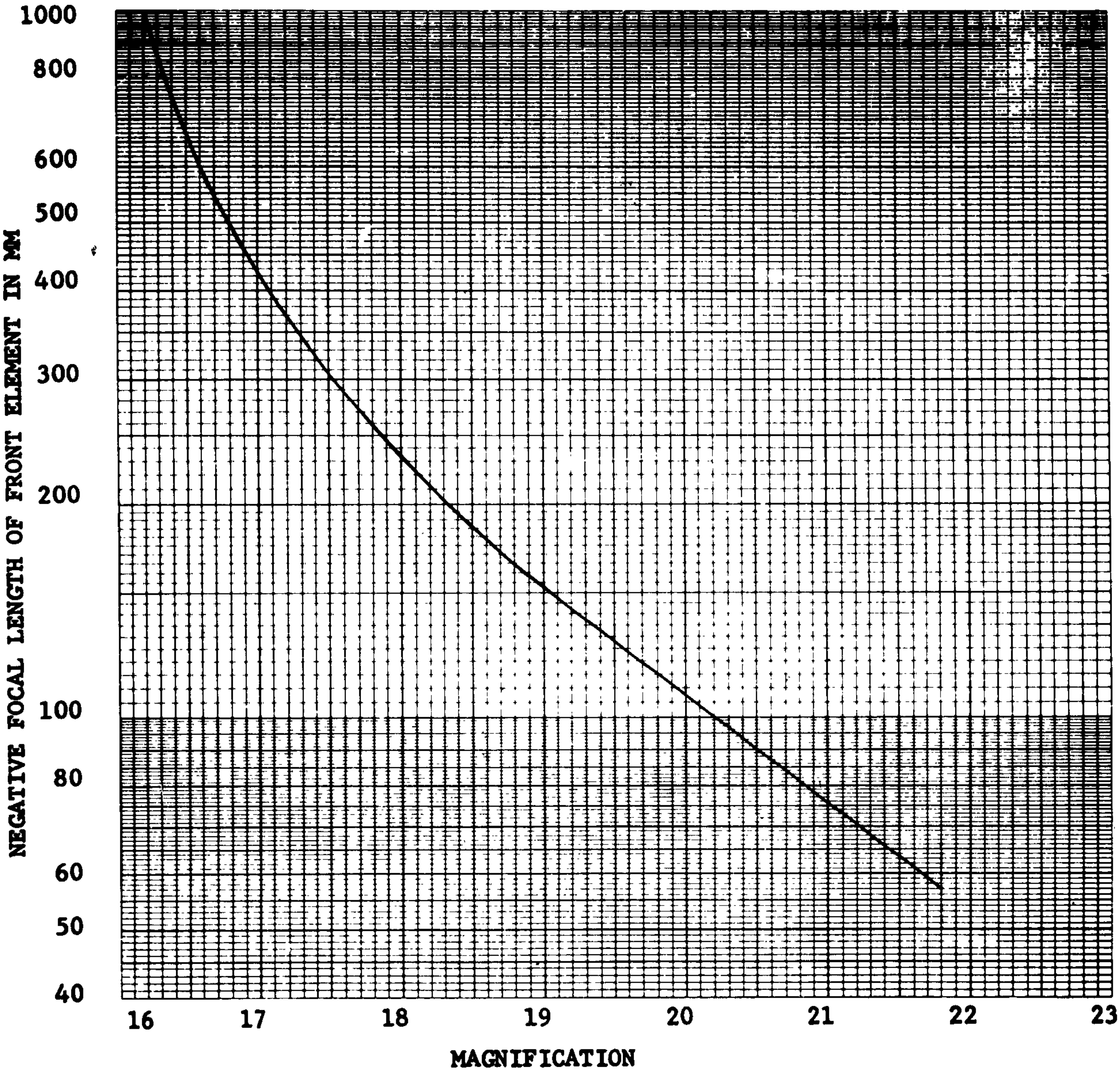


Figure 2-17 SIZE NORMALIZATION CHART

but due to the narrow field angle and the required small zoom range (only $\pm$ 15 per cent change is sufficient), a very simple design should be satisfactory. In fact, a system consisting of only two single elements has been set up at Link on the optical bench in order to examine its feasibility. Both elements must be moved along the axis at different rates to accommodate the desired magnification range but the proper spacing can be easily maintained by means of a cam with the motion actuated by a rotary solenoid or small stepping motor. Since the masses to be moved are small, even in a well corrected lens, and the motions involved are short, it is conceivable that a magnification change could be accomplished in as little as 50 ms. It is believed that with proper optical and mechanical design a very light weight practical attachment could evolve which will meet all requirements for automatic font size normalization.

2.2 RECOGNITION UNIT

The function of the Recognition Unit is to convert the optical character images provided by the Data-Pickup Unit into usable electrical pulse waveforms, compare each incoming waveform against a reference vocabulary of similar waveforms, and indicate as an output signal which reference waveform most nearly matches the incoming signal, thereby identifying the character scanned. The Recognition Unit consists of three major sub-units:

1) Character Digitizer
2) Timing Logic
3) Memory and Readout Logic

2.2.1 Character Digitizer

The heart of the Model X-3 Recognition Unit is the Character Digitizer, which converts the projected image of each character into digital form. To be recognizable, the digital pattern for each character to be read must be generated from horizontal and vertical reference points to the registration of that character.

A simplified block diagram of the Character Digitizer is shown in Figure 2-18. The unit may be subdivided into four basic logic sections as follows:

1) The Pre-Read Logic includes those parts of the system which gather and interpret positional data before the actual start of the recognition process.

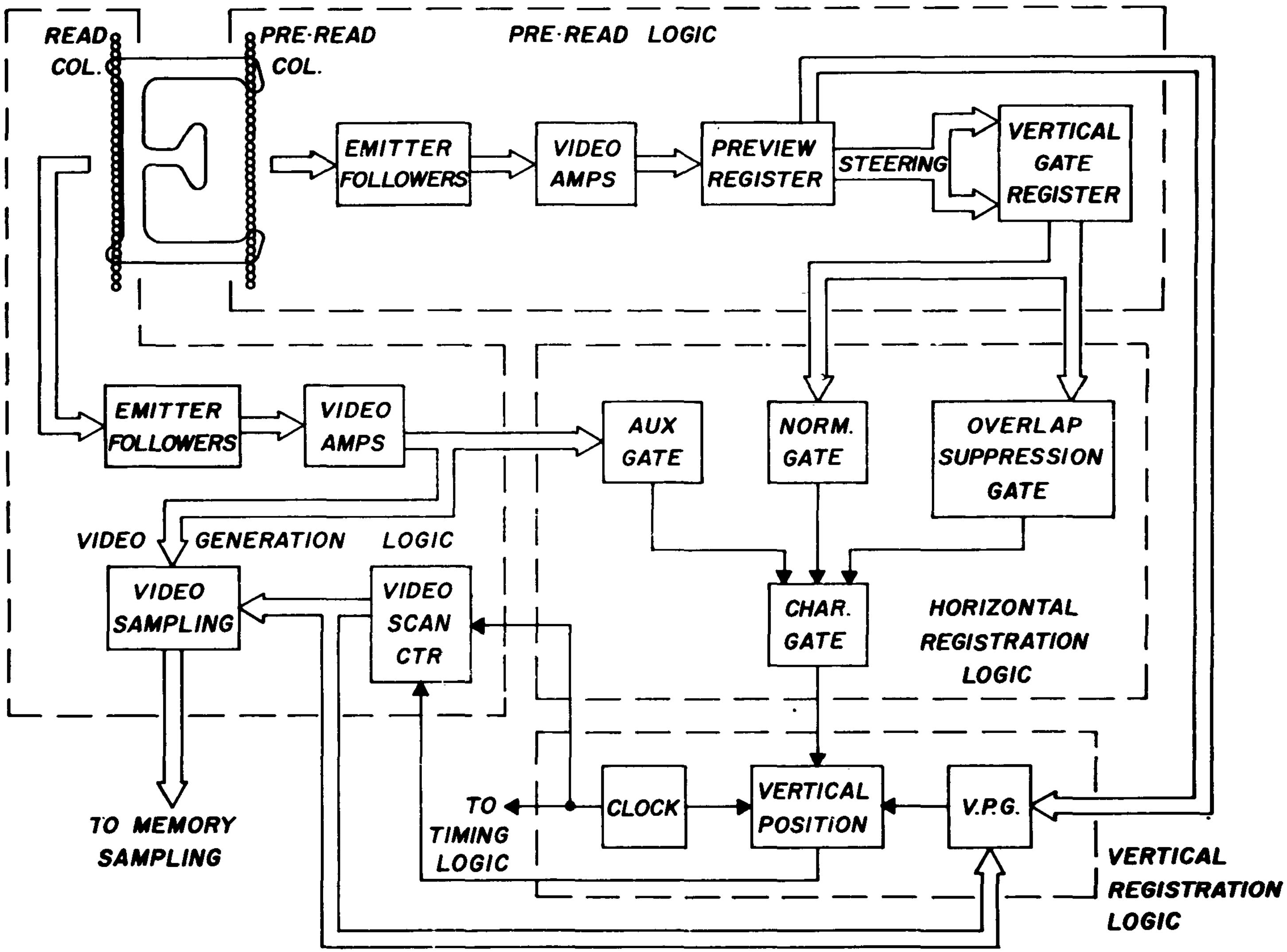


Figure 2-18 CHARACTER DIGITIZER SIMPLIFIED BLOCK DIAGRAM

2) The Horizontal Registration Logic detects the times at which the moving character image enters and leaves the scanning field.

3) The Vertical Registration Logic adjusts the scanning pattern to compensate for vertical image displacement.

4) The Video Generation Logic converts the two dimensional density pattern of the image into the desired digital pattern.

It is suggested that the reader refer to this diagram (Figure 2-18) occasionally for clearer understanding of the following detailed descriptions of the digitizer logic.

2.2.1.1 Pre-Read Logic

The Model X-3 design philosophy requires the dissection of each character into a sequence of bits representing the black and white distribution within the scanning field. Each bit or pulse sequence is then compared serially with similar pulse sequences contained in the machine memory.

To accomplish this, rapid electronic scanning is utilized over the vertical dimension of each character image coupled with slower mechanical scanning over the horizontal dimension. The electronic scanning is accomplished by sequential sampling of a column of photodiodes termed the "Read Column" whose outputs are sequentially gated onto a single video output line while horizontal scanning motion is provided by the rotational movement of the paper transport drum. Successive scans of the Read Column define, therefore, an intensity pattern for each passing character.

A second column of photodiodes termed the "Pre-Read Column" is located parallel to and ahead of the Read Column by a distance slightly less than a nominal character image width. The function of the Pre-Read Column and its associated logic is to establish the vertical character position prior to interception by the Read Column. This establishment of the character image position on the photodiode column allows determination of the area not covered by the character so that overhanging data from adjacent lines can be rejected, thereby minimizing the chances of generating false video information. The basic Image Transducer is illustrated in Figure 2-19, which shows the character image "B" superimposed over the Read and Pre-Read columns.

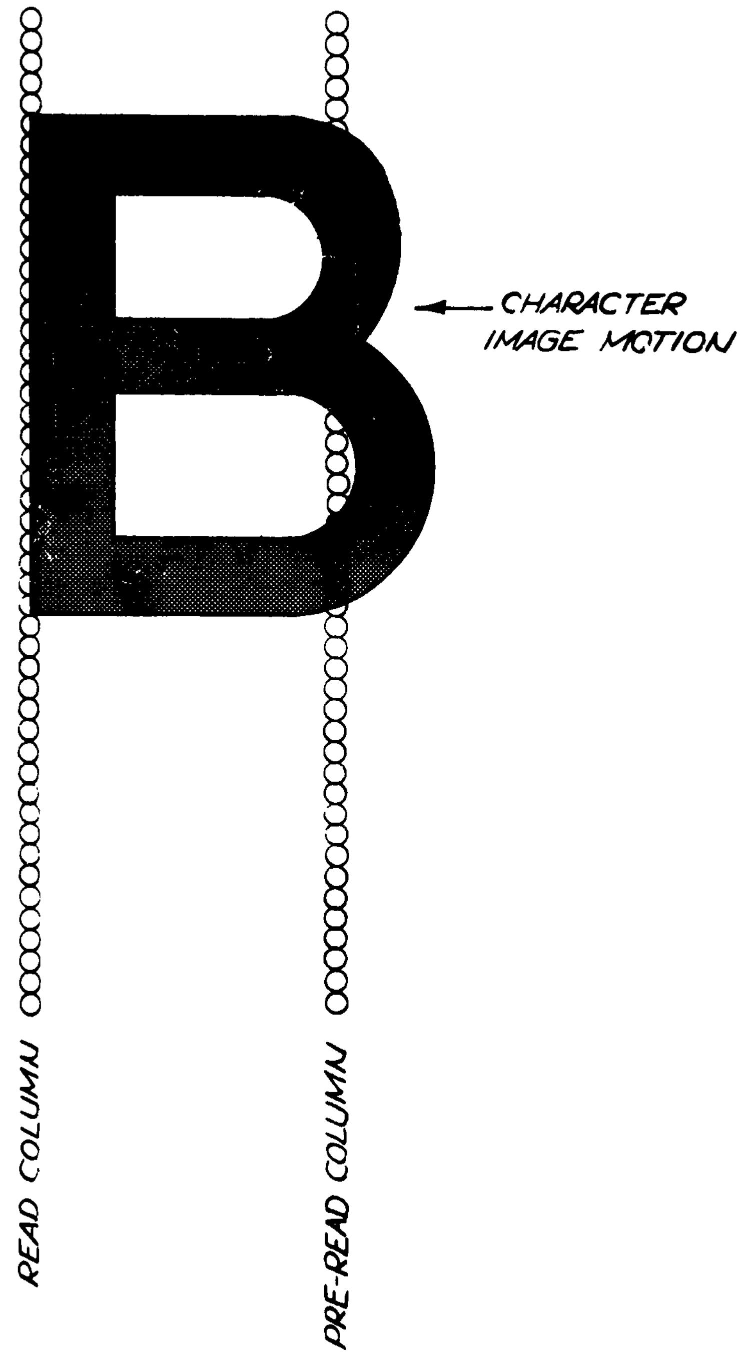


Figure 2-19 IMAGE TRANSDUCER

Two storage registers are employed within the Character Digitizer to establish vertical character position electronically. A "black" indication from the output of any amplifier associated with the Pre-Read photodiodes will set a corresponding stage in a parallel input 48-bit Preview Register. If no character is being read, the information will immediately be channeled into the Vertical Gate Register which loads all of the stored black bits within the vertical dimension covered by the character. Any positional information concerning overhanging data from adjacent lines is eliminated during this transfer of information from the Preview Register to the Vertical Gate Register. This means that if a character in an adjoining line registers at the top or bottom of the Pre-Read Column, the video data describing the position of this unwanted character will be loaded into the Preview Register, but will not be transferred into the Vertical Gate Register since a finite horizontal white swath exists between the desired and undesired characters. In this case the contents of the Vertical Gate Register will only be that data which is related to the character in the line being read. This is illustrated in Figure 2-20. If characters from the adjoining line (either above or below) actually touch or overlap characters in the line being read, wrong information will be stored in the Vertical Gate Register and the machine will indicate a Reject or will misread.

When the character reaches the Read Column, the loading is complete and the inputs to the Vertical Gate Register are inhibited to prevent additional data entry during the read operation. The Preview Register is logically reset by information on the Pre-Read Column within the vertical interval defined by the Vertical Gate Register. Immediately following reset, the Preview Register can resume data storage for the next following character.

2.2.1.2 Horizontal Registration Logic

Since character scanning and memory comparisons are accomplished in real time, Character Gates representing the horizontal registration of each character must be generated as they are read. The leading edge of this gate coincides with the interception of the leading edge of a character and the Read Column. Since the scanning cycle is initiated at that time by this gate its precise timing is very important to the achievement of correct recognition. The termination of the Character Gate (terminating the scanning cycle) is somewhat less critical and is effected in different ways dependent upon how the Character Gate was initiated.

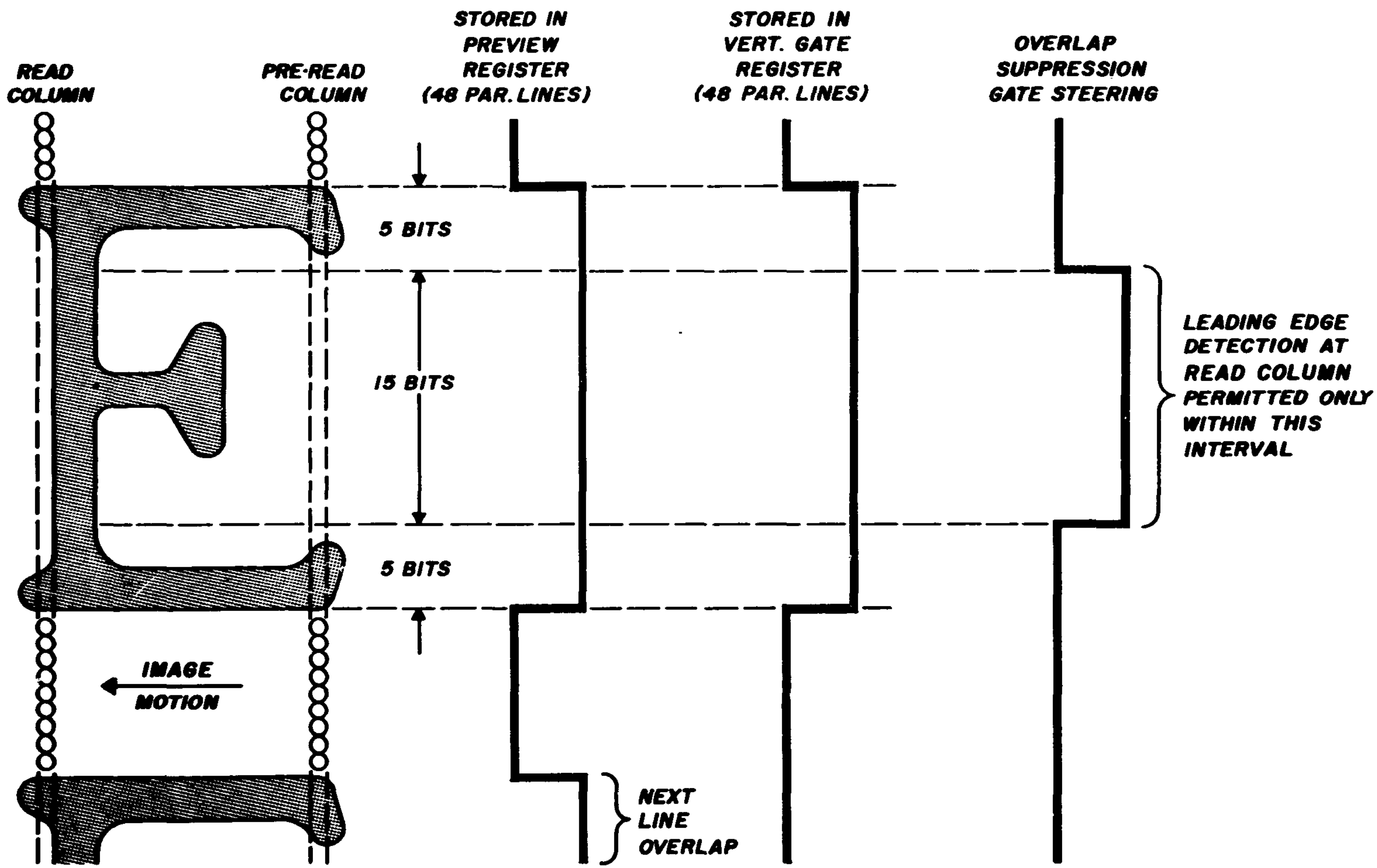


Figure 2-20 TYPICAL PRE-READ LOGIC GATING

Many type styles, such as pica and elite, have serifs at the upper and lower extremities of nearly every character in the font. The vast majority of character overlaps occur in these areas, complicating detection of the leading and trailing edges of a given character. Therefore, a method was devised to ignore these two extremities of the character only when determining the location of the leading edge (and sometimes the trailing edge) of the Character Gate.

While the actual point at which the Character Gate is ended is not critical, certain conditions must be detected in order to satisfy the recognition logic for different characters in the machine vocabulary.

Rough classification of characters is done on the basis of height and width (to be described later). For this reason, it is necessary to determine the width of the character within reasonable tolerances so that only those memory channels describing characters of similar width need be interrogated.

Another consideration is that when scanning a character it is usually desirable to continue the raster even though the character is already past the Read Column. This is true because a more complete comparison of memory data can be made (resulting in greater difference accumulation) if the Character Gate is not terminated earlier than necessary. To achieve this greater reliability, logic is used which results in a minimum of six scans of video data over narrow characters and ten scans over wide characters unless a new character is detected before the end of this period.

Overlaps between characters almost always are caused by serifs and are uncommon in many type styles. Reliable character separation is greatly facilitated by ignoring the portions on the left and right hand edges in which the serifs are expected to occur. Knowing the average character width, the Overlap Suppression Gate need only be sampled after a certain number of scans are completed without detecting a separation. If, however, no separation is found at the Overlap Suppression Gate, meaning that overlap was not confined to the serif regions, arbitrary Character Gate termination is effected. The first character can thus be read while the chances for reading the second character are small though existent.

On the basis of the minimum width of characters in the machine vocabulary, any unknown mark of insufficient width is rejected by noting this at the Normal or Overlap Suppression Gate.

2.2.1.3 Vertical Registration Logic

Before comparison may begin between incoming video information and stored descriptions of each character in the machine vocabulary, the video must be referenced such that each bit will be compared serially with that memory bit which has the same coordinates with respect to the leading and top edges of the character being read.

Vertical referencing takes place during the first scan (Column X), after the initiation of the Character Gate, by sampling the Preview Register outputs sequentially with the Video Scan Counter (VSC). The resulting serial pulse train is used to position the Video Scan Counter at the bit representing the top of the character so that the video will be properly referenced at the start of the second scan (Column A).

The VSC Stop signal inhibits the advance gate of the Video Scan Counter, stopping it on the third black from the top of the character as stored in the Preview Register. This means that if the Video Scan Counter is restarted at the start of Column A in synchronism with the Row Counter, it will be three bits ahead of the Row Counter. This is avoided by inhibiting the Video Counter Advance for three clock cycles (bits A-1, A-2, and A-3).

2.2.1.4 Video Generation Logic

In addition to the vertical referencing of each character as described in the previous section, the Video Scan Counter electronically samples the outputs of the Read Column amplifiers in sequence to produce the serial video pulse train for memory comparison.

A conventional binary counter is used with automatic reset after 48 bits. An input steering network is employed to reduce switching delays, and the entire counter is reset between Character Gates. Figure 2-21 illustrates the counter with steering, reset function, and the 48 buffered decoder outputs.

2.2.2 Timing Logic

The Model X-3 Print Reader employs timing logic which is driven by the clock generator. The primary purpose of this logic is to provide a serial digital count corresponding to the horizontal and vertical coordinates of each video sample relative to the left and top edges of the character.

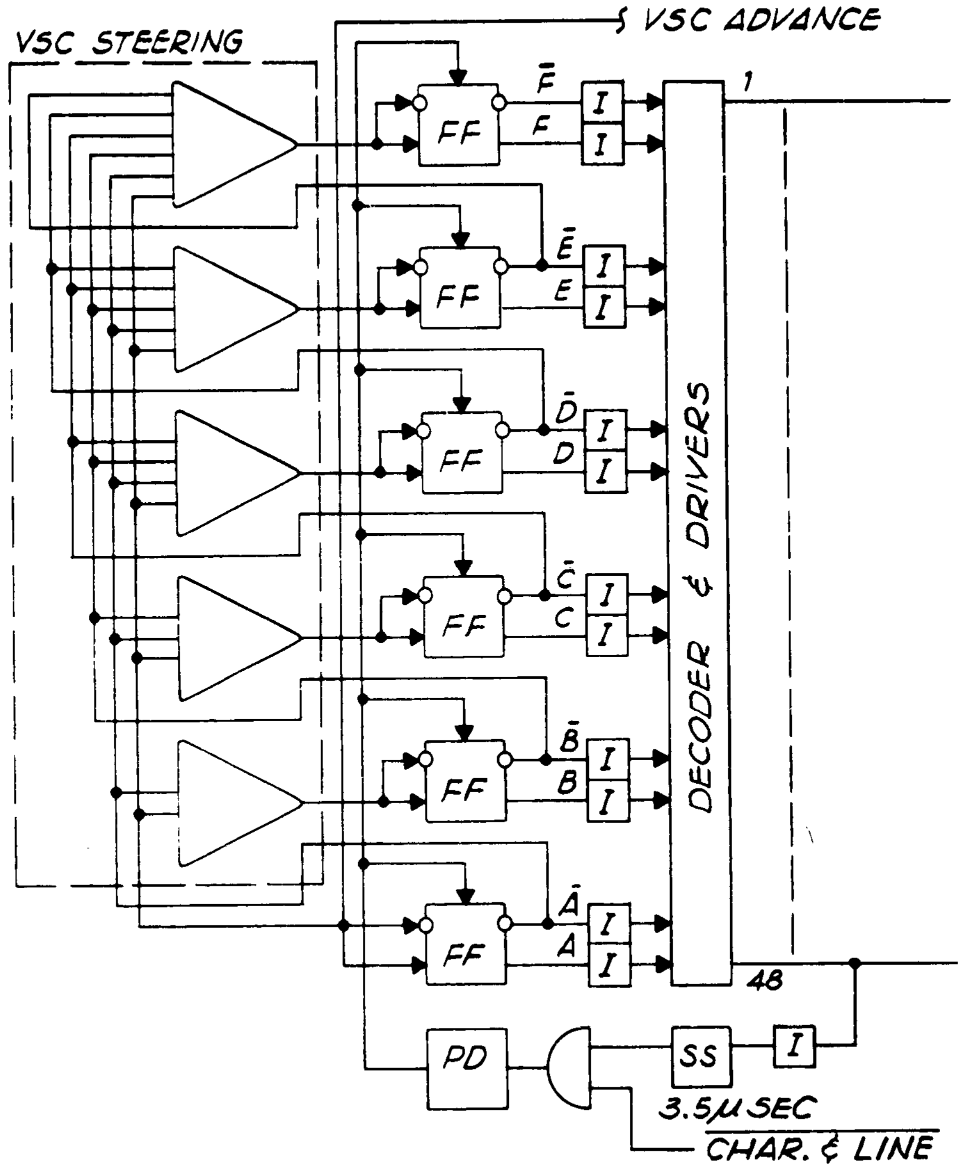


Figure 2-21 VIDEO SCAN COUNTER (VSC) LOGIC

To accomplish this, two counters are employed; a Row Counter and a Column Counter. These counters are started at the initiation of a Character Gate, thus being referenced to the horizontal registration of each character (Figure 2-22). Since there are 48 Read Column photodiodes, the Row Counter counts 48 bits, advancing the Column Counter each time it recycles to the first bit.

In order to create an unvarying sampling pattern, these counters run continuously for the duration of each scanning cycle. After the vertical registration of the character is determined during the first scan (Column X), the serial video data is sampled at preselected bits for detection of dissimilarities from Column A on. Use of the edges of the character for referencing results in nonvarying sampling locations subject only to minor change due to character shape variations, skew, small voids, and moderate addition noise.

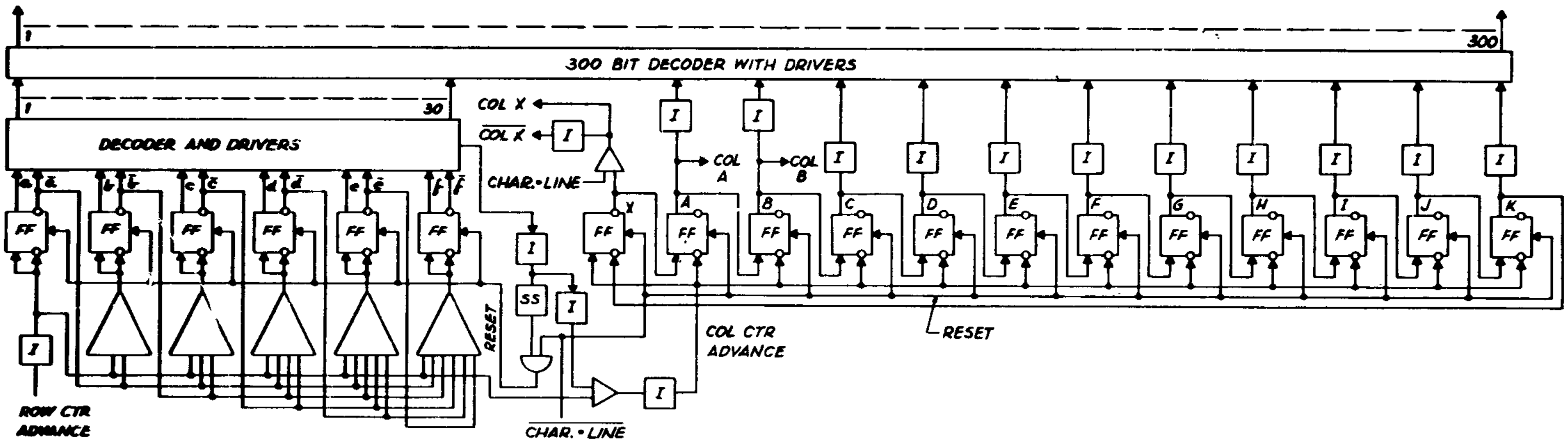
A physical representation of a Typical Scan Cycle is shown in Figure 2-23. The Read Column is shown in various positions relative to the character (the reverse of actual scanning) to illustrate the effect of the timing of the Row and Column Counters relative to the Video Scan Counter and the Character Gate. As indicated, the Row Counter is started at Character Gate initiation, advancing the Column Counter at the start of each 48-bit cycle. However, the Video Scan Counter is preset during Column X at the location of the character top (as described earlier), restarting and advancing in synchronism with the Row Counter during the second scan. Thereafter, the three counters advance continuously for the remainder of the Character Gate period, corresponding to the interval during which the character image is viewed. The Video Scan Counter sequentially samples the Read Column from top to bottom, producing the serial digital video.

Significant advantages of this timing logic over earlier experimental methods are realized. First of all, the pre-read logic enables the vertical reference to be established at the top of the character, while eliminating data from adjacent lines from consideration. Secondly, the comparison of video data from the digitizer is started at a non-varying interval from the Character Gate initiation, irrespective of vertical height or registry (within the column height).

2.2.3 Memory and Readout Logic

The memory of the Model X-3 Print Reader consists of two types of printed circuit cards in a replaceable plug-in unit (Figure 2-24).

Figure 2-22



ROW AND COLUMN COUNTERS

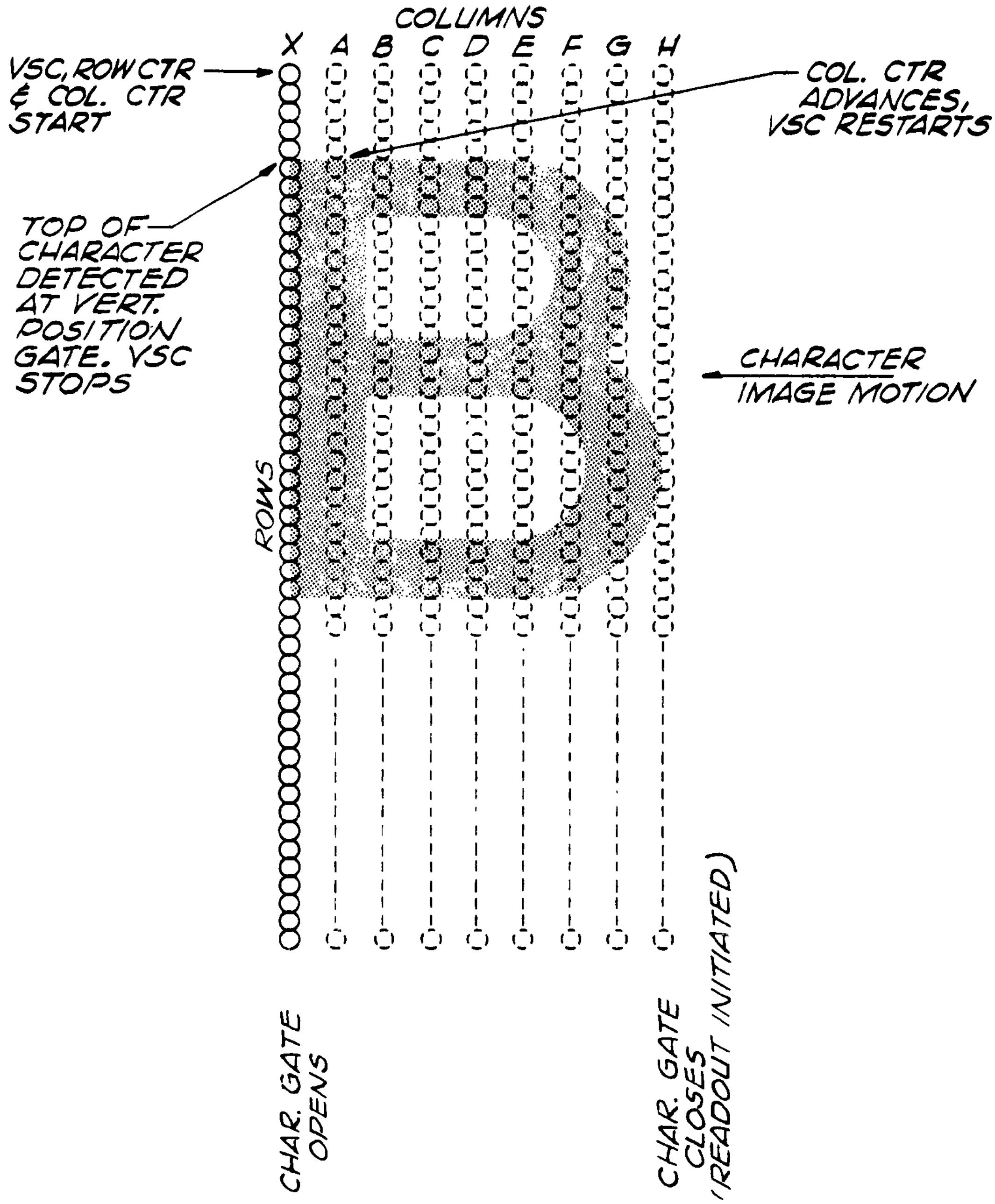


Figure 2-23 TYPICAL SCAN CYCLE

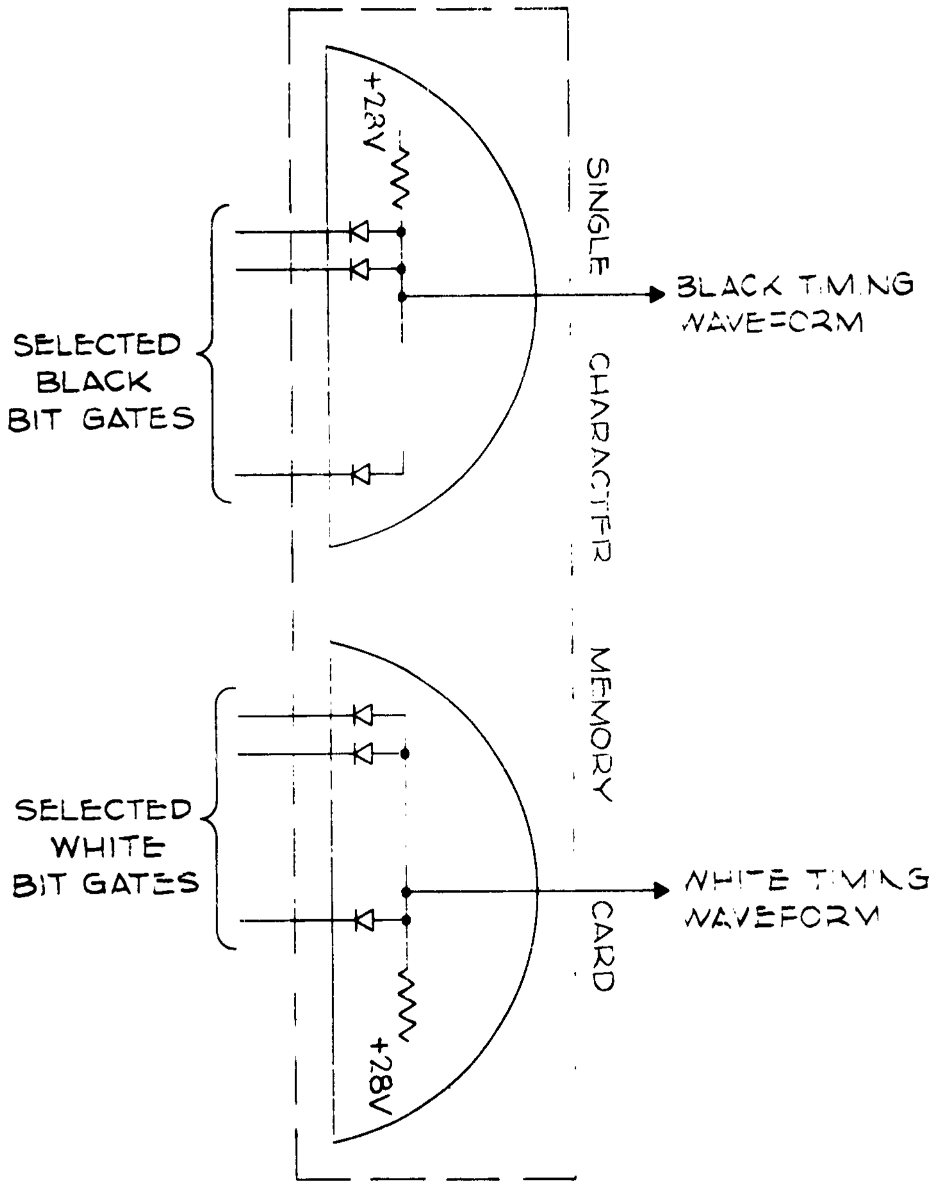


Figure 2-24 MEMORY DIODE GATES

Each card bears two diode gates which can be made up of any combination of diodes, thereby storing any combination of "black" and "white" bits up to a total of 32 on one card type and 44 on the other. Each diode may be connected to any of the 300 decoded bit locations available at the memory input.

The output of each memory channel thus consists of two lines; one carrying all bits encoded as "black" for the particular character, the other carrying all those encoded as "white".

Each pair of outputs enters the Memory Sampling Logic where the selected bits are compared to the video of the character being scanned. This comparison detects the presence of "white" bits in the video where "black" bits have previously been stored and vice versa, resulting in a digital output from any channel whenever such a difference is detected. (Figure 2-25)

These "difference" bits are then accumulated in counting units (staircase integrators) which store a capacitor charge proportional to the total number of differences in each channel. This process is carried out on a parallel basis in as many channels as required for the machine vocabulary.

At the termination of each scanning cycle, the accumulated charge on each staircase capacitor is compared to locate the lowest voltage level. This level should correspond to the character most similar to the one read.

Depending on gross characteristics easily detectable by other logic, only those characters in the vocabulary having similar predetermined general characteristics need be compared using the difference bit technique for selection. This is discussed in Section 2.2.3.1.

Whenever the total number of differences in each output channel exceeds a preselected limit, a separate circuit is used to record this occurrence and prohibit readout of any other channel. This is termed Reject Detection and is discussed in Section 2.2.4.2.

2.2.3.1 Classification Filter

During the development of the Model X-3 Print Reader, it was determined that the maximum number of characters which could be discriminated reliably using only the difference bit technique was approximately 50. Extending this number caused increased leakage currents which prevent proper functioning of the Output Selection Latches.

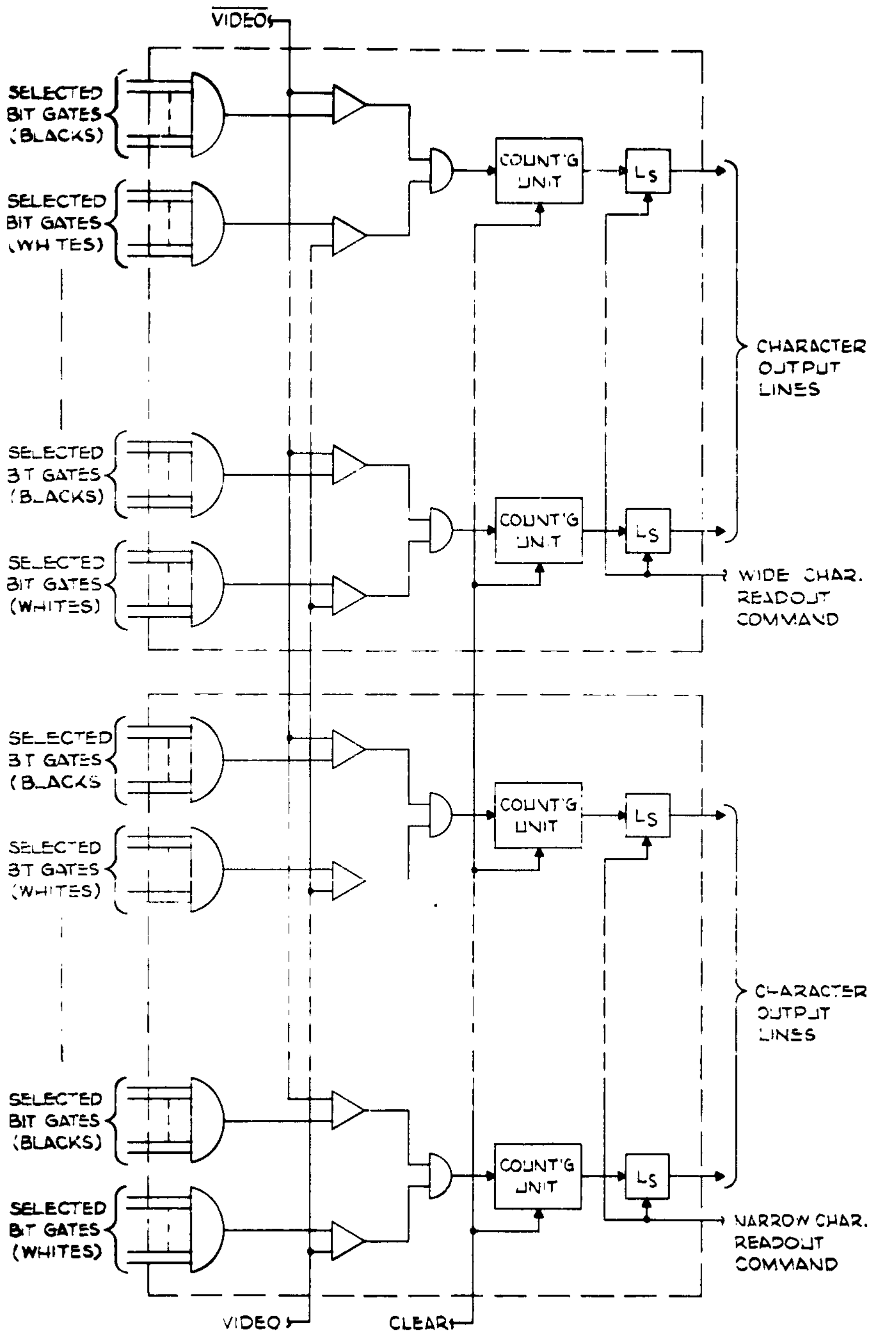


Figure 2-25 MEMORY & READOUT LOGIC

More sophisticated electronic circuitry combined with precision components would be required but was considered to be undesirable. This problem was resolved, however, by sub-grouping the vocabulary on the basis of gross physical characteristics such that discrimination by the difference bit technique was performed on vocabulary groups consisting of considerably less than 50 characters. The Classification Filter is a logical processor that separates characters into sub-groups with respect to their gross physical appearance.

To ensure maximum sensitivity of the Output Selection Latches, it is essential to keep the individual sub-groups of characters small. These selection latches sense the lowest accumulated voltage on the staircase integrators associated with only those characters in the sub-group. All selection latches in a particular group are tied to a common current source and when the associated current source is pulsed, the selection latch with the lowest accumulated voltage turns on and simultaneously inhibits all other selection latches.

Presently, the system incorporates five sub-groups within the 77 character vocabulary. Each character is classified as being narrow and short, narrow and tall, wide and short, or wide and tall. The wide and tall group is further classified on the basis of continuous black or continuous white during the first scan (disregarding voids equivalent to the area covered by two photodiodes). The exact requirements for each group classification are as follows:

<u>Group I (narrow and short)</u>

1) A character that has no black information in the eighth scan, but has black in the third scan, is considered narrow.

2) A character that has no black information in the Preview Register upon occurrence of the 21st row of Column A, but has black in the fourth row, is short.

The characters in Group I are: . , : ' (total of four characters).

<u>Group II (narrow and tall)</u>

1) A character that has no black information in the eighth scan, but has black in the third scan, is considered narrow.

2) A character that has black information in the Preview Register upon occurrence of the 21st row of Column A is tall.

The characters in Group II are: ; () 1 I 7 i (total of seven characters).

Group III (wide and short)

1) A character that has black information in the eighth scan is considered wide.

2) A character that has no black information in the Preview Register upon occurrence Column A, but has black in the fourth row is short.

The characters in Group III are: a c e m n o r s u v w x z * - ? (total of 16 characters).

Group IVa (wide, tall and vertical black stroke in first scan)

1) A character that has black information in the eighth scan is considered wide.

2) A character that has black information in the Preview Register upon occurrence of the 21st row of Column A time is tall.

3) A character has a vertical black stroke in the first scan if three consecutive white rows are not detected between row three and row 20 in Column A.

The characters in Group IVa are: B b D E F H h K k L M N P p R U (total of 16 characters).

Group IVb (wide, tall and no vertical black stroke in first scan)

1) A character that has black information in the eighth scan is considered wide.

2) A character that has black information in the Preview Register upon occurrence of the 21st row of Column A is tall.

3) A character has no vertical black stroke in the first scan if there are three or more consecutive white rows between row three and row 20 in Column A.

The characters in Group IVb are: A C d f G g j J O Q q S t T V W x Y y Z 0 2 3 4 5 6 7 8 9 / # $ % ? (total of 34 characters).

Discrimination within each of the five sub-groups is by the difference bit technique. The Classification Filter, upon inspecting the character being scanned, selects a particular sub-group after which, final recognition takes place by determining the character having the lowest difference bit accumulation.

This grouping of characters according to their physical characteristics makes it possible to keep the groups small and enhances the discrimination capability of the difference bit technique.

2.2.3.2 Character Coding Technique

The present vocabulary of the Model X-3 Optical Reader consists of numerals, upper and lower case letters, punctuation, and special symbols in the Prestige Pica type font (Figure 2-26). Data describing each character falls within a nominal scanning field made up of 10 columns of 25 rows each. Therefore, 250 bit locations are available to define any one of 77 characters.

The total number of bits chosen for reliable recognition of any given character in the 77 character vocabulary varies between 15 and 44 bits. These variations are governed by the size of the group in which the characters appear and by the fact that each character should have a minimum of five best quality differences when comparing the encoded version of any one character against the available bits of any other character in the machine vocabulary. Using diode matrices, the memory requirements of any given character can be assembled on one printed circuit board. Two basic memory cards with standard 35 pin connector or 47 pin connector respectively, provide all necessary input, output, and power connections for the machine vocabulary.

For the Model X-3, the first step in the bit selection process, that of determining all bits of consistent color (invarient video data), was accomplished with a grid overlay on projected character images. The magnification used to enlarge the photographed pica characters was set at 56X. An overlay matrix was designed, having 250 bit locations in the nominal scanning field, which aided the recording and normalizing of video data.

The next step was to convert the bit designations of the enlarged character image into binary form for computer processing. Three binary digits were chosen to quantize the validity of any bit location in the overlay matrix. A set of conventions define each of the possible conditions of bit quality and invariance.

IBM Electric Typewriters bring quality, ease, and speed to today's typing. With only a feather-light touch required to release the electrically-powered keys, unnecessary hand and arm motion has been eliminated. All operating keys - the carriage return, tabulator, shift, and back spacer - are located on the nearly level keyboard and are released with the same light touch. Finest quality of typewritten work, increased speed and ease of operation, and the ability to produce many legible carbon copies are only a few of the advantages of IBM Electric Typewriters.

The keyboard of the IBM Electric Typewriter is designed for the easiest, most efficient typing possible. You'll find you no longer need to "pound" the keys to produce perfect results. You'll benefit greatly from the compactness, scientific slope, and short key strokes of your IBM Electric keyboard because all extra operations are eliminated. Your results will be perfectly uniform - whether you are typing many carbons, a stencil, or statistical work. When you start typing begin slowly. Keep your fingertips close to the keys in a natural, curved position, instead of raising them high above the keyboard.

13579	24680	53579	64246	35791
24680	35791	62480	53793	64884
35791	68436	57579	64246	35775

CODE	MARK	PITCH	LINES/INCH
77	SP	10	5 1/4

Figure 2-26 MODEL X-3 VOCABULARY

Examination of the initial computer results revealed that a certain amount of redundancy existed causing an excessive number of bits to be chosen for discriminating between certain pairs of characters, while only the minimum number (five) was chosen for discriminating between other pairs. This situation arises because the selection is a sequential process. One of the functions that the computer undertakes is the final matrix check. In the search for five differences from every difference matrix, the final matrix check becomes increasingly effective as the total number of chosen bits is augmented. The limited storage of the LGP-30 computer, its inability of sorting the difference matrices starting with that matrix containing the smallest number of differences, and the ineffectiveness of the final matrix check when searching the first few difference matrices, all contribute to the redundant bits in the final coding.

A manual checking and correcting procedure has been developed, however, in which all such cases become readily apparent. The following procedure eliminates all redundancies in an encoded character.

1) Investigate each of the bits in the final character matrix. If the bit in the final matrix is black or white, note which characters in the group have white or black, respectively, in the same position. Note their quality. This information is available in the difference matrices.

2) Sum the differences that should be available between the encoded character and each of the other characters in the group with respect to their quality; i.e., sum the excellent, the good, and the fair bits.

3) Determine those bits from the final matrix that are necessary to fulfill the requirement of five differences between each character using best quality.

4) The remaining bits, if any, can be considered tentatively redundant.

5) Eliminate one of the redundant bits.

6) Determine which of the remaining redundant bits, if any, has become non-redundant.

7) If additional redundant bits should exist, eliminate another and repeat step six.

8) Repeat steps five, six, and seven until all redundancy has been suppressed.

The manual checking and correcting procedure was only used in those cases where the total number of bits in the encoded character matrix was in excess of 44 bits (maximum memory card capacity). This contributed toward keeping the average processing time per character to an economical level.

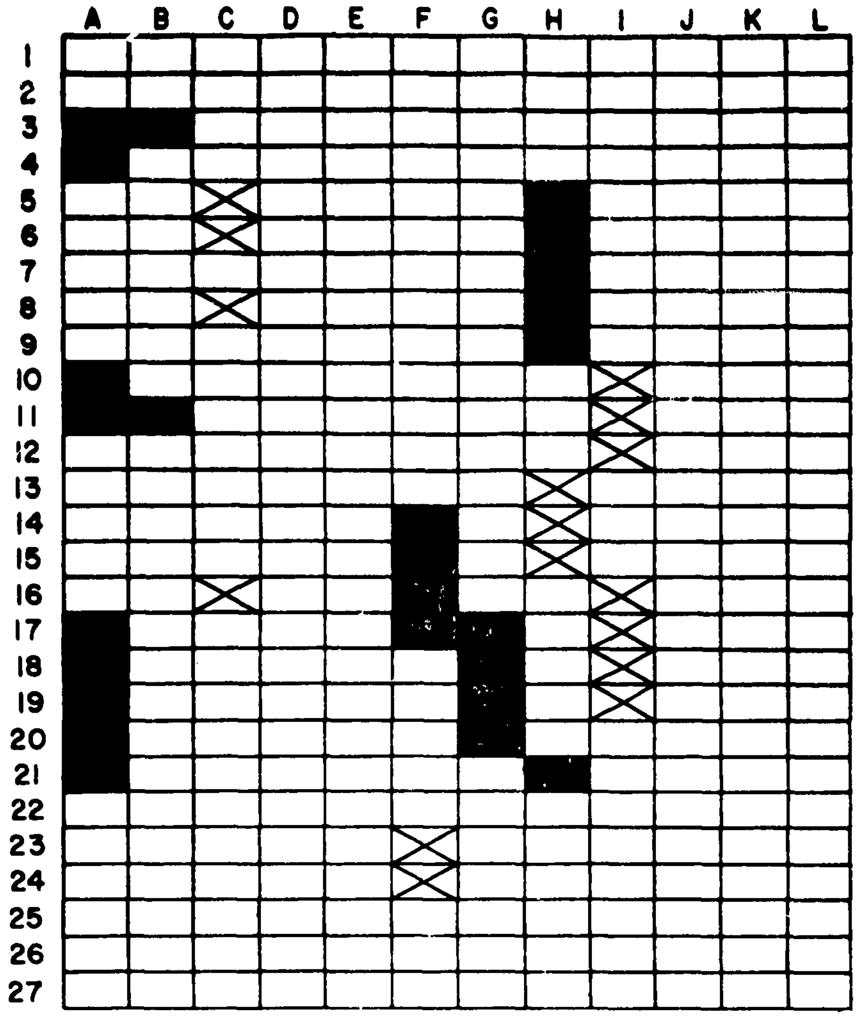
The final encoded version of each character reveals those areas which must necessarily be examined to discriminate the character from other members of the same vocabulary group. Figure 2-27 is the final encoded version of the capital "R", in which case, a total of 42 bits are utilized.

By comparing the encoded version of each character against the available bits (all bits with high color consistency) in the original video data describing the remainder of the vocabulary, tallies of the number of differences were made and recorded in matrix form (Figure 2-28). The matrices contain the characters that are inherent to the respective groups. Four matrices were constructed to show differences between any character pair in the vocabulary.

Group IV has since been subdivided into groups IVa and IVb (see Section 2.2.3.1); however, in the matrix shown in Figure 2-28, both groups are considered as one; i.e., any character in either group has at least five differences when compared with any other character in either IVa or IVb. Coding would admittedly have been more efficient if the subdivision into groups IVa and IVb had been accomplished before the bit selection process. However, readability of a group containing 50 characters was established before the subdivision was made. The most critical pair in this group is the capital "P" and the lower case "p". A total of three differences of good quality are available in either difference matrix, which is sufficient when characters are of good quality.

Group III is a considerably smaller group than group IV and includes one pair having less than five differences. The lower case "x" and the lower case "z" were found to have only four differences when the difference matrices D_{x-z} and D_{z-x}, respectively, were investigated.

The most critical case occurred in group II when the difference matrices D_{l-i} and D_{i-l}, respectively, were formed and found to have only two differences. The existence of these differences depends entirely on the presence of white between the dot of the "i" and the main vertical stroke of the character. In group I, the comma

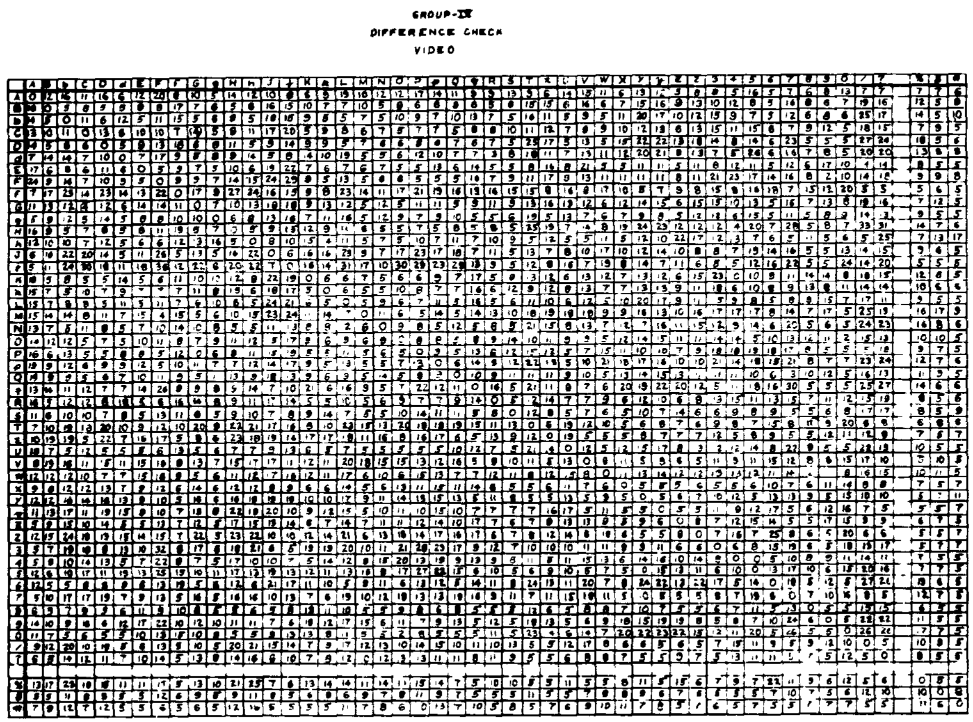


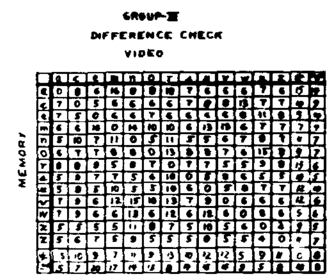
CHARACTER: R
TYPE STYLES: PRESTIGE PICA

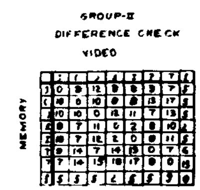
BLACK BIT

WHITE BIT

Figure 2-27 FINAL ENCODING







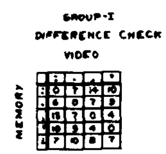


Figure 2-28 CHARACTER DIFFERENCE TALLIES

and apostrophe did not meet the five difference requirement, but reliability is very good with the four existing differences, since group I contains only four characters.

The total time required to completely process one character in the 77 character vocabulary was approximately 3.5 hours. This time can be broken down as follows:

Recording and normalizing video data	0.5 hours
Computer processing	2.0 hours
Manual checking and correcting	1.0 hours
TOTAL	3.5 hours/character

The total hours per character can be reduced by a more powerful computer facility, and a refined method of selecting the most significant bits for each character. A highly refined method has been developed for the Beneficial Management Corporation and has proven to be successful in eliminating the manual checking and correcting phase of the bit selection process. The IBM 1401 computer facility at Link was utilized for that memory encoding operation.

2.2.3.3 Multi-font Reading

The chief obstacle to automatic print reading is the variation in type styles found in printed and typewritten information. In any given application, however, the number of different styles employed is usually limited to a reasonable number. For example, at Link Division, Binghamton, New York, a survey revealed that a total of 83 company typewriters were equipped with seven common type styles, with 47 of these (57 per cent) being IBM Pica, IBM Prestige Pica, and Royal Pica machines. These fonts are highly similar.

A certain amount of style and/or stroke width variation can be compensated for by the aforementioned character coding technique. That is, if a sufficient number of invariant video exists between the same characters in different type styles, single character codings can be made to apply to each character, regardless of type style variations. This was verified experimentally in the Model X-2 machine where twelve alphabetic characters could be reliably read in any of three type styles using only a single stored digital description of each character identity.

Proof has also been documented during this study program showing that a 36 character font consisting of upper case alphabet and numerals from two highly different type styles, Artisan 10 and Prestige

Pica, can be instrumented using this same composite coding approach. For this method to be effective, the type styles must be of approximately the same size and aspect ratio. Where size differs considerably, a means for size normalization must be provided (Section 2.2.7.3).

When character styles differ greatly, they may be treated as entirely different characters using a separate printed circuit card for each. For instance, the "B" differs greatly in overall character width in the IBM Pica and Prestige Pica type styles. These could be handled most readily by incorporating two separate character codings with the outputs of both channels logically combined. When a "B" is encountered in either style, then readout would signify a "B" regardless of style.

It was also demonstrated in this program, that the entire machine memory can be made as a pluggable module such that additional complete vocabularies can be interchanged. This approach can be used when type styles to be read are numerous and differ too widely for the use of composite codings. The printed circuit cards peculiar to any given vocabulary are also pluggable units allowing not only complete interchange of vocabularies, but the change of any particular character in a vocabulary.

2.2.3.4 Alternate Memory Considerations

An investigation was made concerning the possibility of using a memory medium other than the diode memory such that vocabulary changes could be made without physically substituting printed circuit cards or replacing the entire memory package as is now required. It would be extremely desirable, for instance, to have the capability for loading different vocabularies into the reading machine from a library of type fonts stored on punched paper tape or cards. Therefore, two common programmable memories were considered - magnetic drum memory and magnetic core memory. Before discussing drum and core memories in detail, the characteristics of the presently used diode memory will be reviewed.

2.2.3.4.1 Diode Memory Characteristics

The diode memory is physically composed of a number of diode gates mounted on plug-in boards and wired by standard printed circuit techniques. A single board defines a character in memory. Each character board has assigned to it significant information bit time slots varying in number from a minimum of 15 to a maximum of 44. The time slots vary from character to character and are selected

from a matrix of 10 x 25 (250) possible positions. Time slots for a given character are checked sequentially during any given character scan and in synchronism with the character scan frequency. A gate may or may not be physically included on a board at a given time slot in accordance with the way the character is encoded.

If, at a particular instant in time relative to the input video pulse train, a gate exists in the corresponding time slot of a particular character board, an output is produced on one of two lines from the board defining either a black or white bit for that position. A pulse output will also be gated out of all other character boards on which that position is defined as either a black or white bit. If a particular time slot for a given character is determined to be insignificant or of inconsistent color, no gate (diode) is included on the board for that position and no pulse can result in that time slot at either of the character board outputs. The storage of only selected black and white bits results in a memory whose time slots can assume three possible conditions: black, white, or neither.

Memory scanning is done in real time synchronism with character scanning; therefore, memory access time must be virtually instantaneous. Otherwise, intermediate video storage must be included.

The substitute memory then should exhibit the following characteristics:

A. Provide immediate sequential interrogation of all stored characters simultaneously.

B. Provide pulses on two output lines per character, one representing stored black bits and the other stored white bits.

C. Be capable of having its internal format changed by programming to accept new character shapes.

D. Be economically competitive with the diode memory.

2.2.3.4.2 Magnetic Drum Memory

Operation of a drum memory system does not usua[illegible] place in real time. When required to do so, the usual p[illegible]re is to use a temporary storage buffer that can be loaded at the input rate and interrogated at the drum rate. Probably the most straightforward method for instrumenting this is to use two buffers, each large

enough to accommodate one complete character pulse train describing the widest vocabulary character. Buffer A can be loaded while Buffer B is being unloaded and vice versa. Then, with unloading taking place at a drum rate much faster than the input rate, a sufficient amount of time can be allowed for drum access. The input pulse repetition frequency is determined by the character scanning rate, and buffer interrogation must be accomplished in less time than required to scan characters having the smallest physical spacing. The time allowed between interrogations is the access time.

Figure 2-29A is a rudimentary timing diagram of the load-unload cycle of two input Buffers A and B. The worst case, in which the least amount of time is available, would be while scanning a series of characters having the smallest physical spacing. Character #1 would be loaded into Buffer A at the bit rate of the Reader. As soon as the End of Character is sensed, the input to Buffer A is closed and Buffer B is enabled to receive Character #2. If memory access time were instantaneous, the time available to unload Buffer A would be the loading time of Buffer B, which is equal to the scanning time (T) for Character #2. Since there is a finite wait before the required memory data is available from the drum, the rate of unloading from the buffer must be speeded up accordingly. If the access time were equal to T_A, the unload cycle must be completed in less time that $T-T_A$. This shown in Figure 2-29B. It can be seen, therefore, that access time can be traded for buffer readout rate, and vice versa.

Using a drum, the minimum access time that can be achieved is to have the complete memory available every bit time. This, however, is impractical in this as well as most other applications. Assuming a 100 character vocabulary each having 250 time slots (bits), and assuming separate tracks for black and white information, there would have to be 100 by 250 by 2 equals 50,000 time slots of storage available. A drum having 200 tracks for data storage, plus several timing tracks, would accommodate the 100 character vocabulary. At this point, the cost of the drum system electronics is already rather formidable. Assuming $15 per head and $100 for each associated amplifier, more than $23,000 is invested in components exclusive of Buffers A and B and the magnetic drum itself.

In order to define the desired drum characteristics, the desired operating parameters for the reading machine must be specified. At a reading rate of 500 characters per second, the time required for scanning one character is nominally two milliseconds. Therefore, the complete memory must be interrogated and the contents of

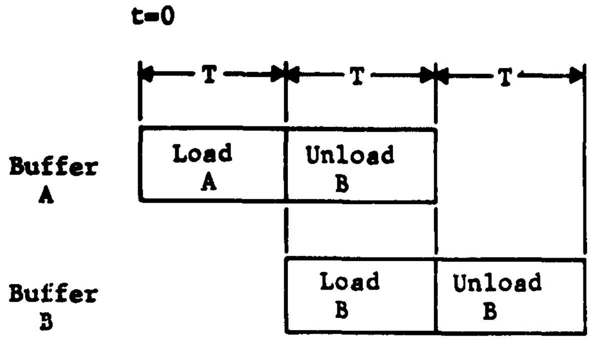
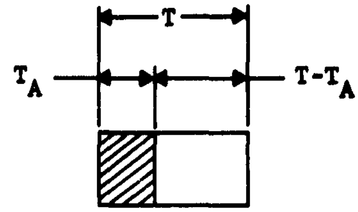


Figure 2-29A



T = Character Scan Time = Buffer Load Time = 2ms
T_A = Drum Access Time
$T-T_A$ = Maximum Buffer Unload Time

Figure 2-29B

BUFFER LOAD & UNLOAD CYCLES

SPECIFICATION	DRUM A	DRUM B
Speed (RPM)	6000	12000
Diameter (inches)	10	4
Bits Per Inch	125	125
Bits Per Track (125π D)	3930	1570
Character Words Per Track (Bits Per Track ÷ 250)	15	6
Seconds Per Revolution	0.01	0.005
Drum Access Time (T_A) (Sec Per Rev ÷ Words Per Track)	666μ sec	833μ sec
Buffer Unload Time ($T-T_A$)	1334μ sec	1167μ sec
Unload Frequency [250 ÷ ($T-T_A$)]	192.5 KC	214.5 Kc

Figure 2-29C TYPICAL DRUM SPECIFICATIONS

either buffer read out in something less than two milliseconds. Any waiting time taken up by access time to the memory reflects itself as a required increase in the readout or unload rate of the buffer registers.

Figure 2-29C shows some drum relationships based on a recording density of 125 bits per inch. The assumption is made that two tracks are used per character, one for black and one for white information, and that a complete character pulse train is 250 time slots long. Since more than 250 bits can be stored on the drum circumference, the information is repeated as many times as possible giving a corresponding reduction in access time.

Use of a magnetic drum as the memory medium for a Universal Print Reader appears to be quite feasible and would conceivably offer the advantage of field programming of the reader vocabulary. However, the complexity and associated high component cost offset this advantage to a large extent. Conservative manufacturing cost being one of the primary objectives of this program, prevented further development of the drum memory approach.

2.2.3.4.3 Magnetic Core Memory

The limited access time characteristic of a magnetic drum would not be present in a magnetic core memory system. Therefore, the need for Buffers A and B, as described in the previous section is eliminated.

A programmable core storage system is also technically feasible, but would offer no competition to the diode memory system in terms of complexity and cost. A complicating requirement as in the drum system is the need for essentially ternary storage in which "black", "white", and "don't care" must be designated. A core plane would, therefore, be required for black bits, as well as white bits, totaling two core planes per character, each with a storage capacity of 250 bits. The complete core memory for a 100 character vocabulary would have a capacity of 25,000 bits and at an estimated cost of at least one dollar per bit, the memory components represent a $25,000 investment. Here again, economic considerations prevented further development of a programmable magnetic storage medium.

2.2.4 Special Circuits

2.2.4.1 Space Detection

In the reading of characters, readout is initiated by detection of an all white vertical column following the character just scanned

or by detection of a finite character width, whichever occurs first. The sensing of spaces, on the other hand, cannot depend on what is on the document, but rather must be detected by the lack of video data either for a period of time or for a fixed horizontal distance.

The method used for detecting spaces relies specifically on the time during which characters are not sensed. The space detection circuit on Figure 2-30 is designed to indicate the presence of one or two or more spaces, therefore, signifying the separation between words, sentences, and columns of printed information. Successive spaces in excess of two are recorded as two spaces, so as to prevent wasteful use of the output record media when scanning large blank areas.

Operation of the space detection circuit is based on pulse width sensing where a fixed time duration t is recognized as signifying a single space while a pulse duration equal to or greater than 2t is recognized as signifying two spaces. A level of minus 10 volts on the input line (no character present) causes a ramp voltage to be generated having a known voltage gradient. Two threshold detecting amplifiers are used to detect levels A and B corresponding to time t and 2t respectively. Thus, if no character is encountered during the interval t, a single space is indicated and if none occurs in the interval 2t, two spaces are indicated. The eventual occurrence of a character resets and holds the ramp generator and space output line in the off condition.

2.2.4.2 Reject Detection

A special channel is employed which detects and signifies a reject when the number of differences in every character channel of the selected vocabulary group exceeds a preset threshold. This channel is identical in all respects to other character channels within the group except that an adjustable voltage source is used as its input. This voltage setting establishes the net accumulated difference count above which, a reject is indicated.

For example, if an ideal letter "A" was scanned, the accumulated difference count in the "A" channel would be zero, while all other channels of the vocabulary group would accumulate five counts or more. The "A" would, therefore, be selected and read out. If, however, the "A" was highly mutilated and the reject threshold was adjusted to four difference bits, a reject would be detected and read out since the "A" channel, as well as all other character channels, would probably accumulate five or more differences.

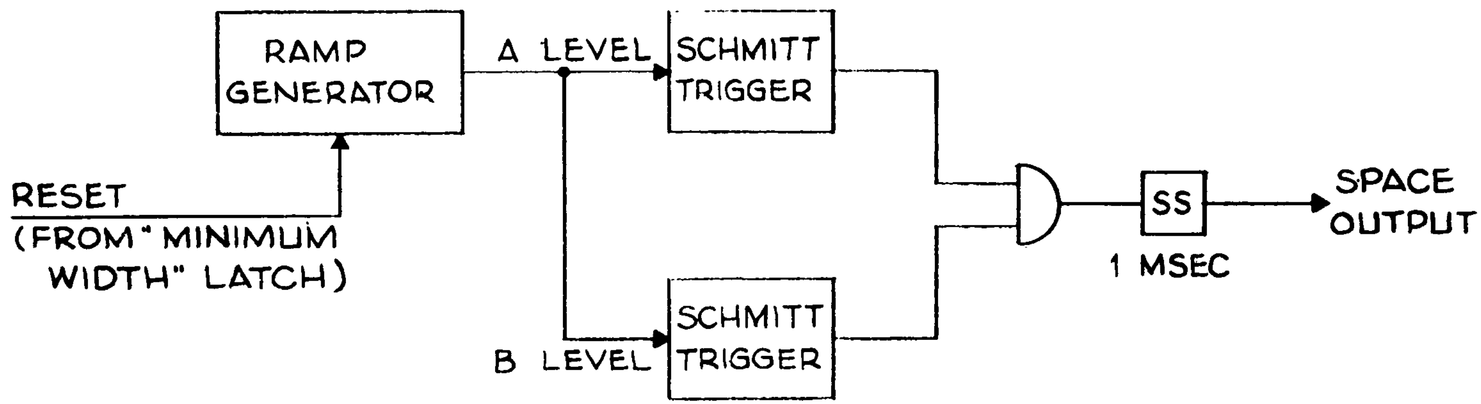


Figure 2-30 SPACE SENSING CIRCUIT BLOCK DIAGRAM

The continuously adjustable feature of the reject control permits tradeoff of reject rate for error rate and vice versa. With the reject threshold control adjusted to one difference bit, the machine error rate should be absolutely zero since effectively perfect characters are then required for recognition. This would result in excessively high reject rates in most applications, since machine printed characters are seldom perfect or ideal.

The optimum setting of the reject threshold can best be determined through machine reading of actual documents of the intended optical scanning application. The reject threshold control can then be adjusted such that reject and error rates are within required limits.

2.3 OUTPUT UNIT

The Output Unit requirements for demonstrating successful operation of the Model X-3 did not justify the purchase of a paper tape or magnetic tape recording unit for machine development purposes. Actually, neither of these devices is well suited toward aiding the development of a reading technique since neither provides a recorded output which is easily interpreted visually unless playback is effected through some display device such as an output typewriter or high speed printer.

For the purposes of this study, an output configuration was developed which provides a real time indication of reading performance at reading rates from five to more than 500 characters per second. The configuration consists of a Link developed character generator used in conjunction with a storage oscilloscope providing a temporary display of all Recognition Unit decisions in page format. As information is read it is written electronically on the face of the storage oscilloscope. The data can be photographed if a permanent record is required and it can be erased completely by a simple contact closure.

2.3.1 Character Generation and Display

The Character Generation and Display device composes alphanumeric characters, or any arbitrary pattern of lines, on the screen of a cathode ray tube, where the display is in the form of closely adjacent luminous dots positioned to generate the required line patterns and the character selection and display position order signals are in the form of decimal digital codes. The system offers good readability, high writing speed, flexibility, relative simplicity and reasonable cost.

In generating characters, the blanked electron beam is positioned at the sub-origin of the character by X and Y component deflection voltages. Dot positions are measured from the sub-origin and relative deflection voltages from resistor networks, are added to the previous major deflection voltages. The beam is unblanked when it has been driven to the pre-determined dot position. The character to be displayed is thus synthesized by a series of overlapping dots.

This type system is flexible in that new characters or symbols can be added by calculating the corresponding resistor networks using simple scaling or interpolation. No analyses of wave shapes are necessary nor is a new mask or CRT required.

Writing speed is faster than that of raster scanning systems and comparable to that of the systems using CRT masks. Brightness is better than most other similar character generation systems if the same beam current and accelerating voltage are used. Character shape and definition are superior because each dot can be positioned as desired, without degenerating the rest of the character, unlike raster scanning and harmonic synthesis techniques.

A completely transistorized system was constructed to display 40 characters on the screen of a commercial oscilloscope. The 40 characters include the letters A through Z, numerals 0 through 9, and four special characters.

The method of operation for the display of one character can be seen from the condensed block diagram illustrated in Figure 2-31. A display order pulse, T_o, causes reset of the code storage units and triggers a delay multivibrator to furnish a delay equal to the settling time of the deflection system for a major deflection input. Immediately after T_o, the codes for character selection and display position orders are received and sent to the storage units. The X and Y major deflection storage units operate precision transistor switches, which drive major deflection resistor networks to produce the required analog inputs to the X and Y amplifiers to bring the beam position to the required suborigin point. The character code storage unit operates the character code matrix to produce a positional output for the selected character, which drives the appropriate push-pull driver unit which, in turn, drives the corresponding X and Y precision diode switches. During this time, the dot counter is in zero space, so that no dot deflection signals will appear through the open switches.

After completion of the delay period of the multivibrator, a delayed output, T_1, will set a toggle which opens an "and" gate to permit 30 KC (or higher) clock signals to drive the dot counter from zero state towards its maximum state. In the present embodiment of the system, 40 characters may be selected for display with a maximum of 19 dots required for the display of any single character. The dot counter drives a dot matrix which provides additional outputs to sequentially drive 19 X and 19 Y precision transistor switches, as well as providing one input to a turnoff gating unit. This unit also is driven from the character selection matrix so that for a selected character which required, for example, nine dots for display, a turnoff signal will be generated at the tenth dot time, resetting the toggle and the dot counter in readiness for the following character orders.

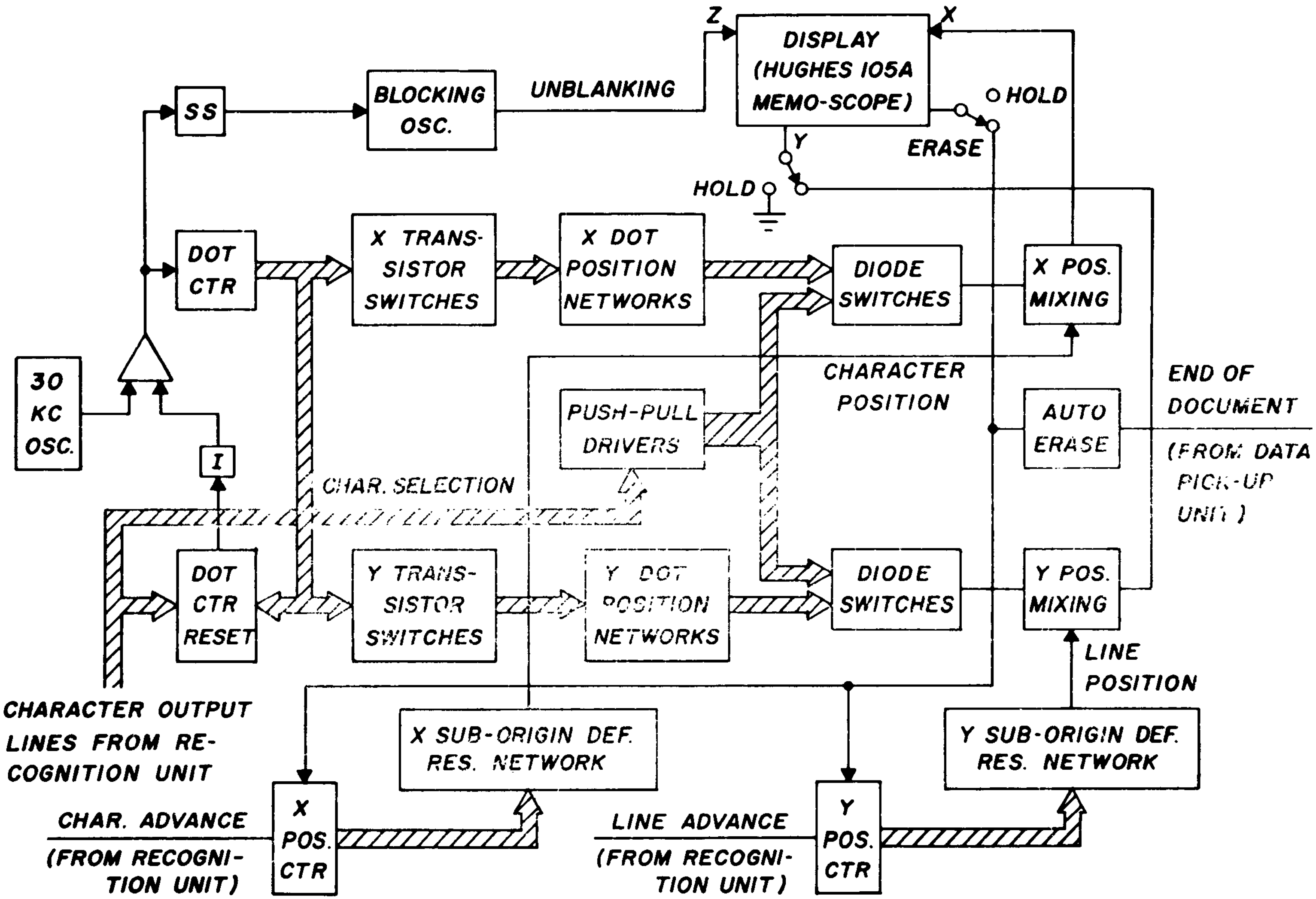


Figure 2-31 CHARACTER GENERATION & DISPLAY BLOCK DIAGRAM

The dot drive signals from the X and Y transistor switches drive the associated resistor of each of 40 dot deflection resistor networks. For example, a signal from the X transistor switch driven by the "one" output of the dot matrix, will drive the first resistor of all 40 networks which furnish the X components of the 40 characters, while that from a switch driven by the "19" output of the dot matrix, will drive only two of the 40 networks, since all other display characters required a lesser number of dots and will have had a turn-off signal generated before the "19" state is reached. The output of the dot deflection resistor network for the selected character will pass through the closed diode switch to generate a minor deflection voltage along one axis and similarly for the other component. Figure 2-32 illustrates the resistor summing network for the letter "T", which contains nine dots.

The counters (flip-flops), decoding diode matrices, and gates are conventional digital circuits. Signal levels are such that minus ten volts is designated as binary 1 and no voltage as binary 0. The turn-off diode logic is made of "or-and" circuits in parallel and merged to a single "or" circuit that triggers the one shot multivibrator. The diode logic block cycles the dot counter according to the number of dots assigned to a character. Thus, the system starts forming the next character without the delay that would occur in a system with a cycle time fixed to accommodate the character requiring the largest number of dots.

The resistor networks of Figure 2-32 are easily calculated by laying out the desired characters or symbols on graph paper, as illustrated in Figure 2-33. Each character is assigned a 6 x 6 centimeter square with suborigins, as indicated. Dot centers are measured from the suborigins. The coordinates of these values are inversely proportional to the corresponding resistors.

2.3.2 Output Devices for Data Processing Applications

Most applications for optical scanning require either punched paper tape or magnetic tape as the recorded output record. In some instances, the output might be fed directly to the input of a computer or be reprinted using other type styles and/or format, however, these are presently considered special requirements and will not be discussed in detail. Punched card output is sometimes required, but in far fewer instances than paper or magnetic tape. These latter devices are, therefore, the primary output devices for Universal Print Reader applications.

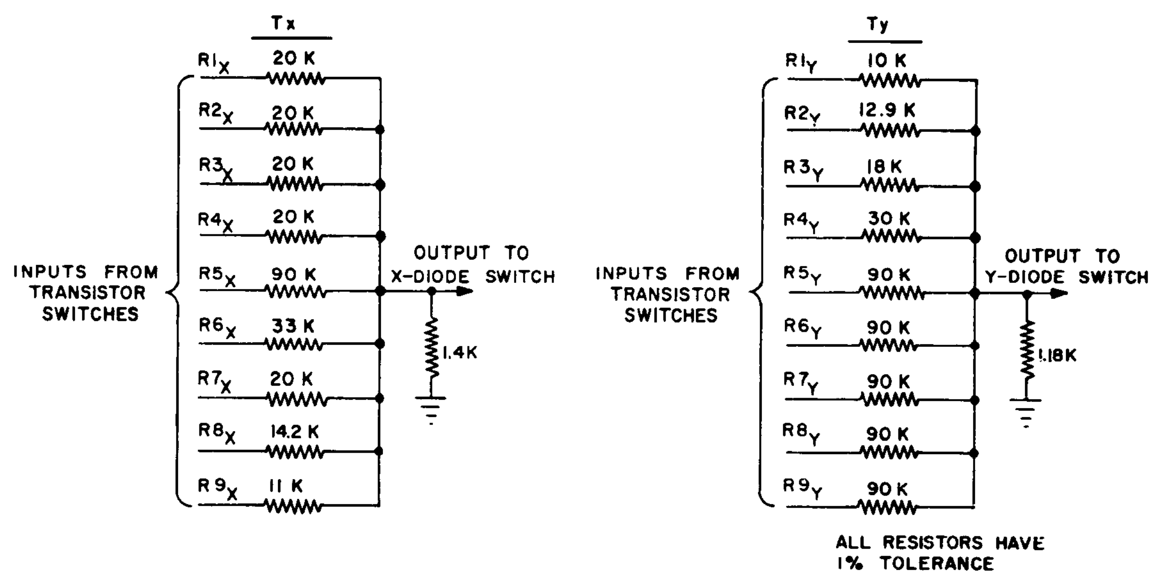


Figure 2-32 RESISTOR SUMMING NETWORK FOR CHARACTER "T"

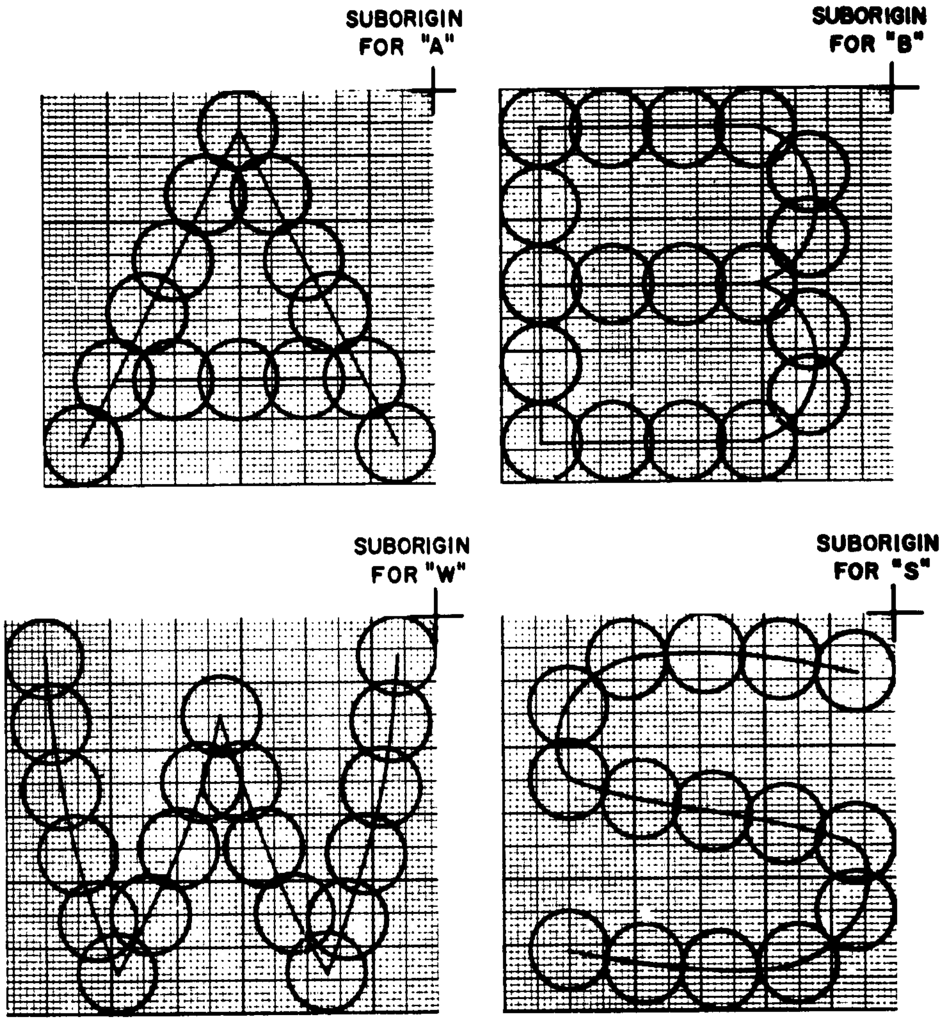


Figure 2-33 COMPOSITION OF CHARACTERS

2.3.2.1 Paper Tape Perforator

With the addition of appropriate encoding circuitry, several commercially available tape punches can essentially be directly substituted for the presently used Character Generation and Display Unit. The Recognition Unit converts characters into electrical signals, character-by-character and line-by-line, permitting the tape punch to be driven in synchronism with each character identification without additional buffer storage. The scanning rate can be adjusted to the rated tape punch speed, which ranges from 20 to 300 characters per second on presently available units.

2.3.2.2 Magnetic Tape Unit

A magnetic tape unit can be used to provide output from the Model X-3 compatible with any type electronic computer desired.

Digital recording on magnetic tape is usually done at high tape velocities (100 inches per second) and high recording density (333 characters per inch), which results in a typical recording rate of more than 33,000 characters per second. High recording rate is desirable from the standpoint of efficient tape utilization and to minimize computer time used during subsequent playback. The print reader, however, cannot be made to operate synchronously at this rate of speed, primarily because of paper handling limitations. Therefore, buffer storage is required between the Recognition Unit and the tape station, which permits accumulation of large blocks of data at the scanning rate and transfer of this data at the tape station rate. Buffer storage also provides the possibility of adding a RESCAN MODE to the print reader to reduce reject and error rates and permit certain editing routines without wasting tape by recording unnecessary data. For page reading application, a core buffer unit appears most suitable with data input and retrieval on a bit-parallel, character-serial basis.

2.4 DEVELOPMENT AIDS

2.4.1 Automatic Character Analyzer

The memory encoding process used during the development of the Model X-3 utilized character data obtained by overlaying a representation of the scanning raster on magnified character images. Each bit position was then designated as being black, white or marginal, depending upon total or partial color consistency within each bit as defined by the overlay. Although a working reading machine has been constructed using this method, it was realized

that the technique has many disadvantages which undoubtedly resulted in non-optimum character codings. The major weaknesses in the overlay technique are as follows:

1) Top and left edge scanning references on each character are established by human judgement and are, therefore, subject to error.

2) In order to obtain a usable image size, a photographic transparency is made of each character to permit magnification with a standard projector. Photography introduces error because of integration of character detail.

3) Because of the large amount of manual labor involved in this process, data is based on a single or, at most, two or three impressions of each character. Therefore, differences which arise among many typewriters, due to type bar manufacturing tolerances, are not accounted for.

4) Color designation of each individual bit is a matter of human judgement and is, therefore, subject to error.

5) The effect of character skew on the color designation of each bit is not easily determined.

To facilitate future memory encoding operations, a system has been developed which performs the data-taking portion of the task automatically with all of the above disadvantages eliminated. The system is appropriately termed the Automatic Character Analyzer and requires for its operation a working Data Pickup Unit, Character Digitizer, and Row and Column Counter units of the Timing Logic, as described in previous sections of this report. A block diagram of the Automatic Character Analyzer is shown in Figure 2-34.

Since the Analyzer uses, as its inputs, video and timing signals from the actual scanning mechanism and associated electronics of the reading machine, the human element has been removed from the data recording process. Scanning references are established and bit color is decided by the reading machine. Also, the number of character impressions scanned can be very large (100 or 1,000) and can be taken from a variety of machines, even with different type styles, if desired (the output record would then be a composite indication of color consistency for each bit position when scanning the same character in diferent type styles). The Automatic Character Analyzer has been designed to utilize input signals derived from the Model X-3 Page Reader and performs the following operations while any series of characters is being scanned:

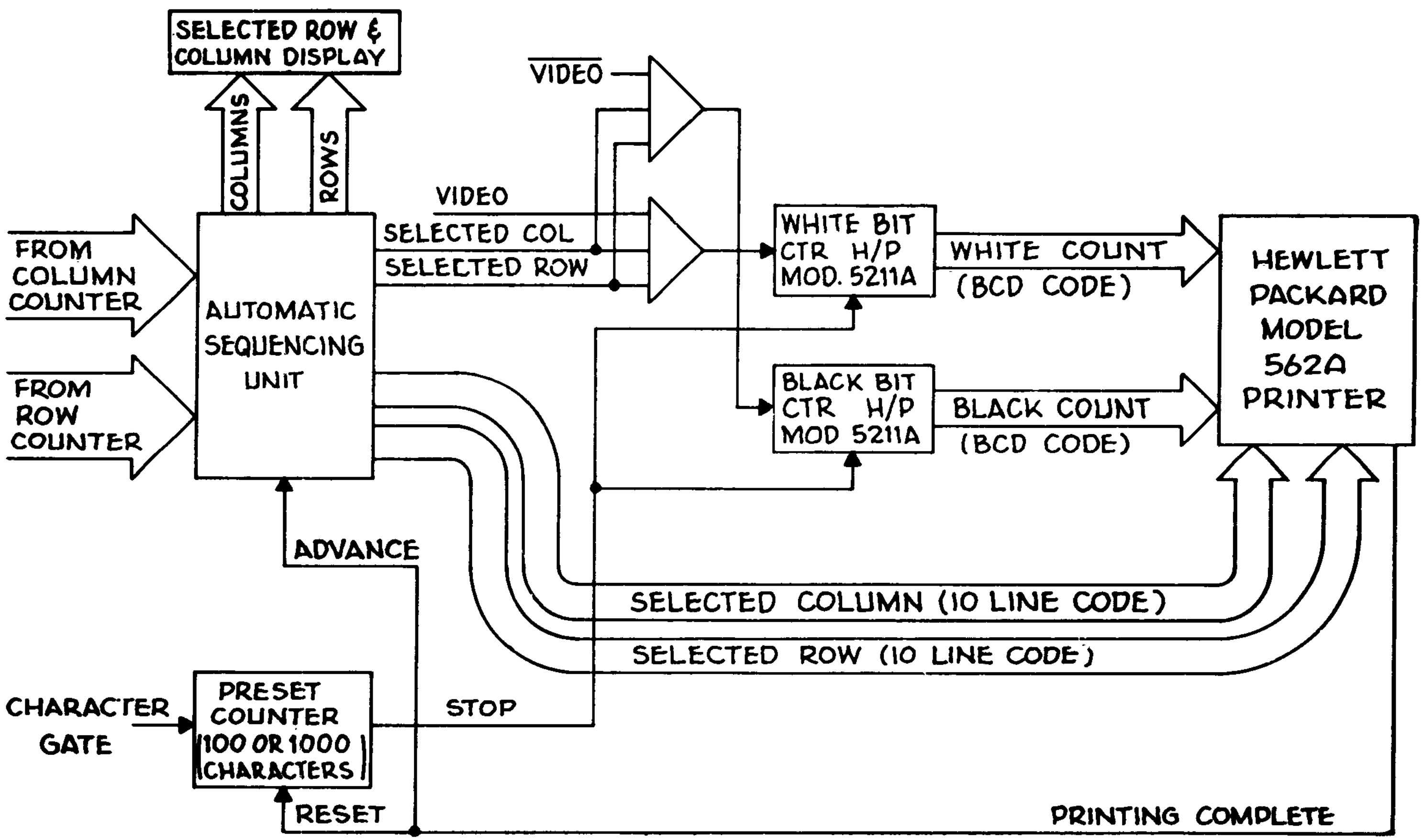


Figure 2-34 AUTOMATIC CHARACTER ANALYZER

1) Counts and displays the total occurrence of white for each bit position within a preset count of 100 or 1,000 characters.

2) Counts and displays the total occurrence of black for each bit position within a preset count of 100 or 1,000 characters.

3) Selects and displays rows one through 30 sequentially and automatically.

4) Selects and displays columns A through P sequentially and automatically.

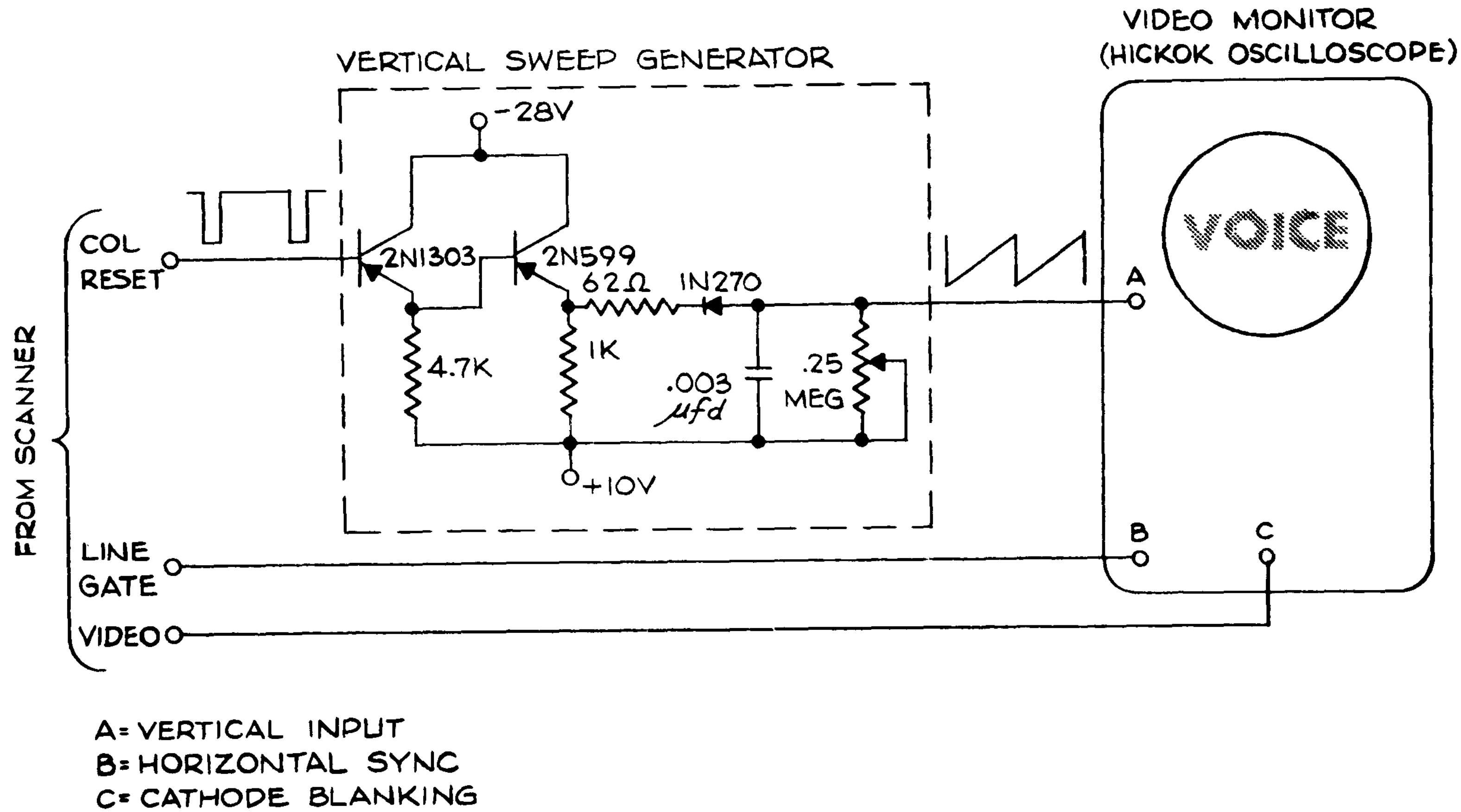
5) Provides a sequential printed output, which includes column identification, row identification, total occurrence of white and total occurrence of black for each bit position (particular row within a particular column).

The processing time necessary to produce a 300 bit sequential digital description of a single character is about two minutes, using a preset sampling of 100 times for each bit position.

2.4.2 TV Display System

In order to obtain a real-time indication of exactly the information being viewed and recorded by the scanning system at any instant, a display system was designed to visually present the data bit by bit, as recorded by the scanner. An oscilloscope is used as the viewing device, with vertical and horizontal sweeps being generated in synchronism with the vertical sweep and document motion of the scanner. The system is shown in Figure 2-35, which includes a schematic of the circuit used to generate the vertical sweep signal.

The image visible on the monitor device (a conventional oscilloscope) is an exact duplicate of that actually recorded by the scanner and is of great benefit in evaluation of problems, and in improving certain logical schemes in the system.



TV DISPLAY SYSTEM

Figure 2-35

2.5 DOCUMENT QUALITY CONTROL

2.5.1 Reflectance Measuring Equipment

For optimum reading performance, documents should be characterized by high contrast between character impressions and paper. Careful selection of the type of paper used helps to ensure adequate contrast and is especially important when re-usable ribbons are employed in the machines producing the documents to be scanned. Reflectance measurements within the range of spectral sensitivity of the reader photosensors provide, therefore, one important basis for paper selection.

The response of the photodiodes (T.I. Type LS400) used in the reader peaks sharply at 800 millimicrons, therefore, the reflectance measuring apparatus shown in Figure 2-36 is designed to be effective only in the vicinity of this wavelength. Most of the system is made up from commercially available components. Reflectance measurements have been found to agree closely with costly recording spectrophotometers.

A cutaway view of the complete equipment is shown in Figure 2-37 and consists of four units:

1) The measuring sphere, including photomultiplier,
2) The indicating instrument, which is used as a micro-ammeter,
3) The power supply and amplifier, and
4) The tungsten light source with filters.

Samples are inserted beneath the cover on top of the integrating sphere using a flat black backing material. The white reflectance standard is magnesium carbonate, a block of which is used to calibrate the indicating instrument to 100 per cent reflectance.

Good quality paper for optical scanning exceeds 80 per cent reflectance in the vicinity of 800 millimicrons. Many paper samples of different grade and weight have been found to have acceptable reflectance. However, when other characteristics,such as ribbon compatibility, ease of feeding, erasing characteristics, etc., are considered, the number of acceptable samples narrows considerably. Not all commercially available paper has been examined for these features; however, one type which has been found acceptable in all areas is SCAN-51-YY1 "Scanamaster" manufactured by the Oxford Paper Company.

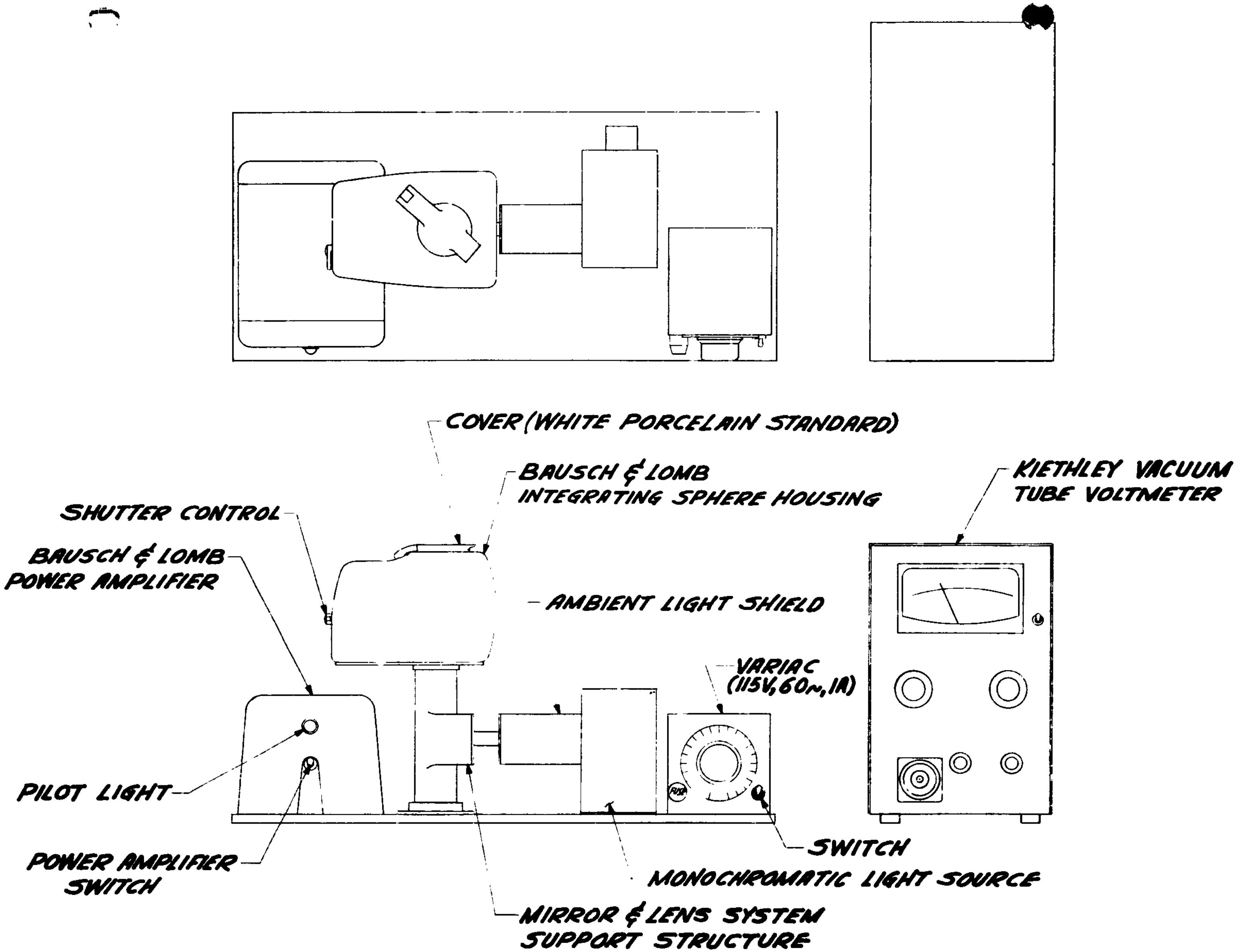


Figure 2-36

REFLECTOMETER ANALYSER ASSEMBLY

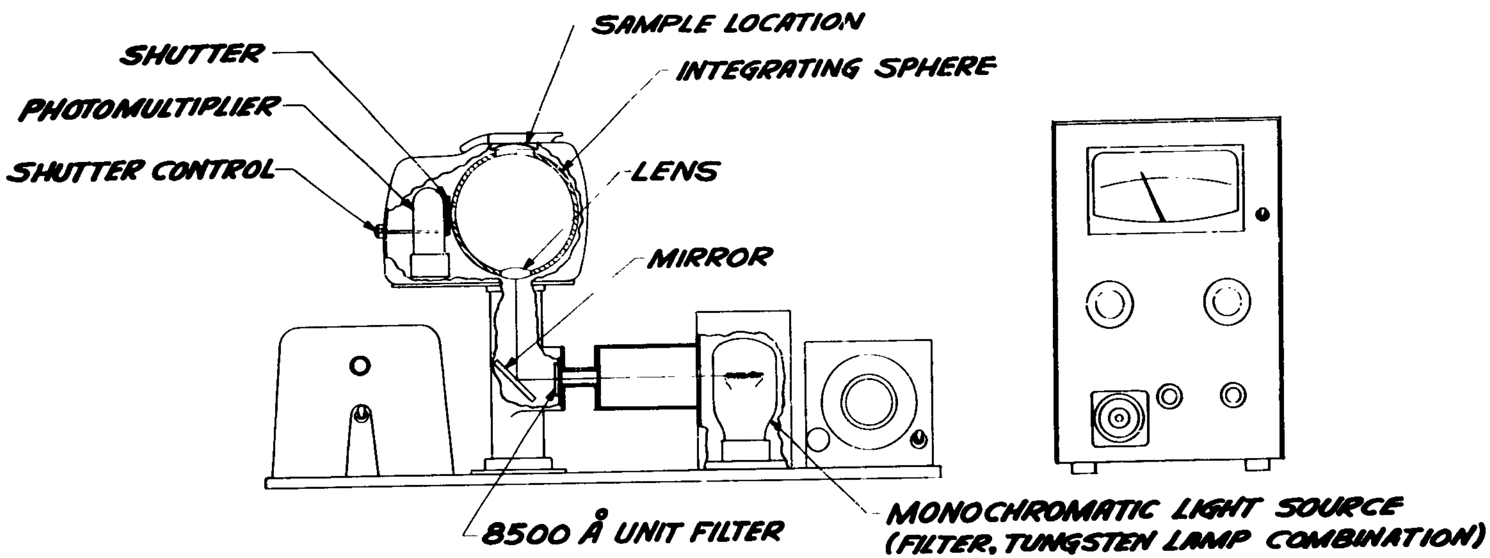


Figure 2-37 OPTICAL CUT AWAY (REFLECTOMETER)

2.5.2 Reading Pre-printed Forms

Pre-printed text or lines on the documents which have no significance to the scanner should ideally have the same reflectivity as the paper itself; they will then be "invisible" to the scanner. It has been found that a correct mixture of red and white inks can simultaneously be highly visible to the human eye and practically invisible to the scanner.

Two excellent "drop-out" colors are Splendid Red, mixed one to ten with white, and ML 117, made by Van Son Holland, Inc., Mineola, New York. A reflectivity diagram of the latter is shown in Figure 2-38, and a typical scanning form prepared with Splendid Red in Figure 2-39.

Several other colors besides red can be used for various purposes, such as cancellation stamp initialling and check marking. With proper color choice there is no need to restrict placement of stamps or marks, since they cannot be seen by the scanner. During the printing process the set-off of extraneous ink must be controlled. Better drying inks and suitable care taken by the printer minimize this condition. An ideal document should not show any background set-off by ink or carbon.

For maximum efficiency, forms should be arranged so that the information to be read is confined to consecutive lines to facilitate machine programming. This also minimizes the time lost in searching for data or skipping fields.

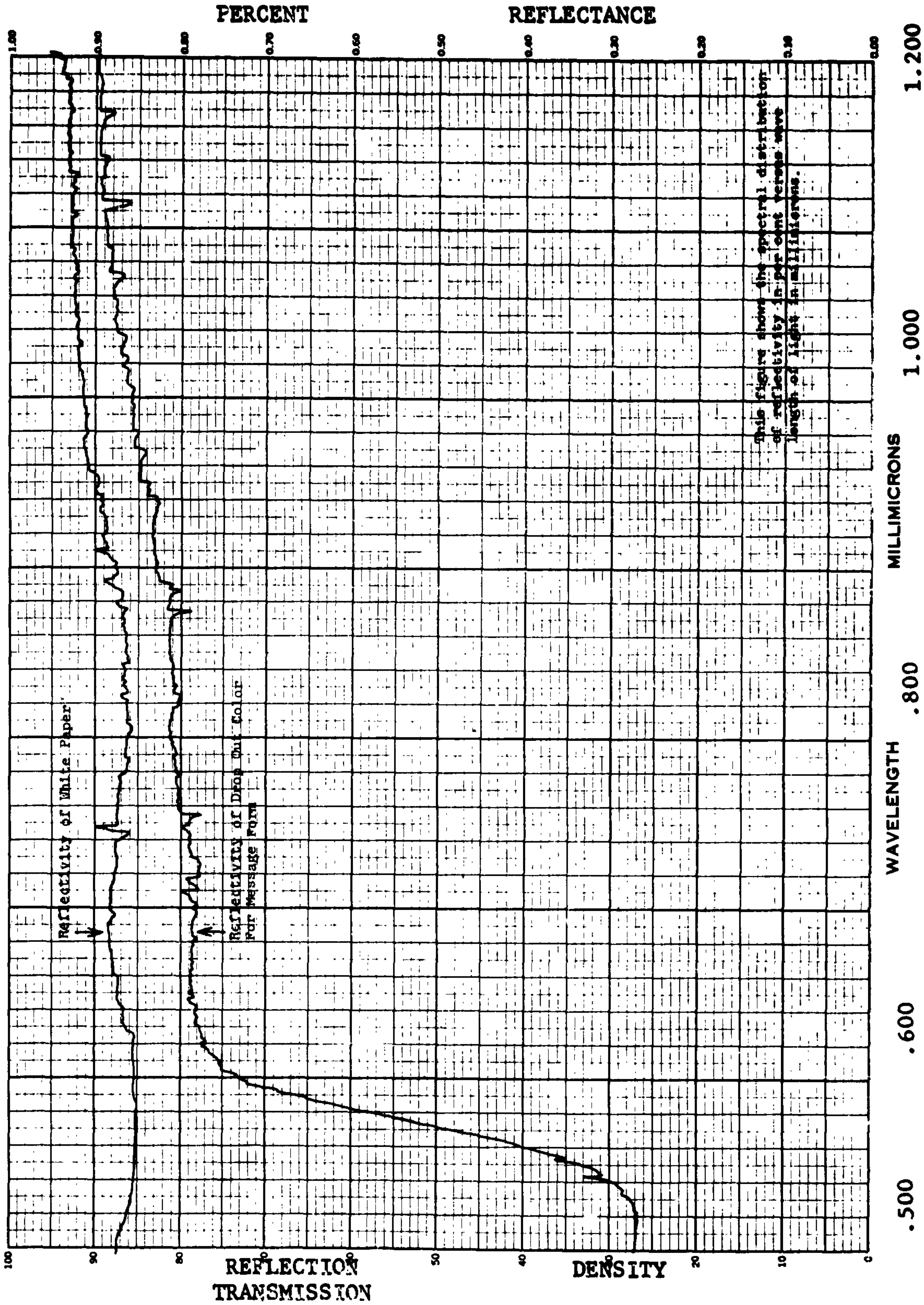
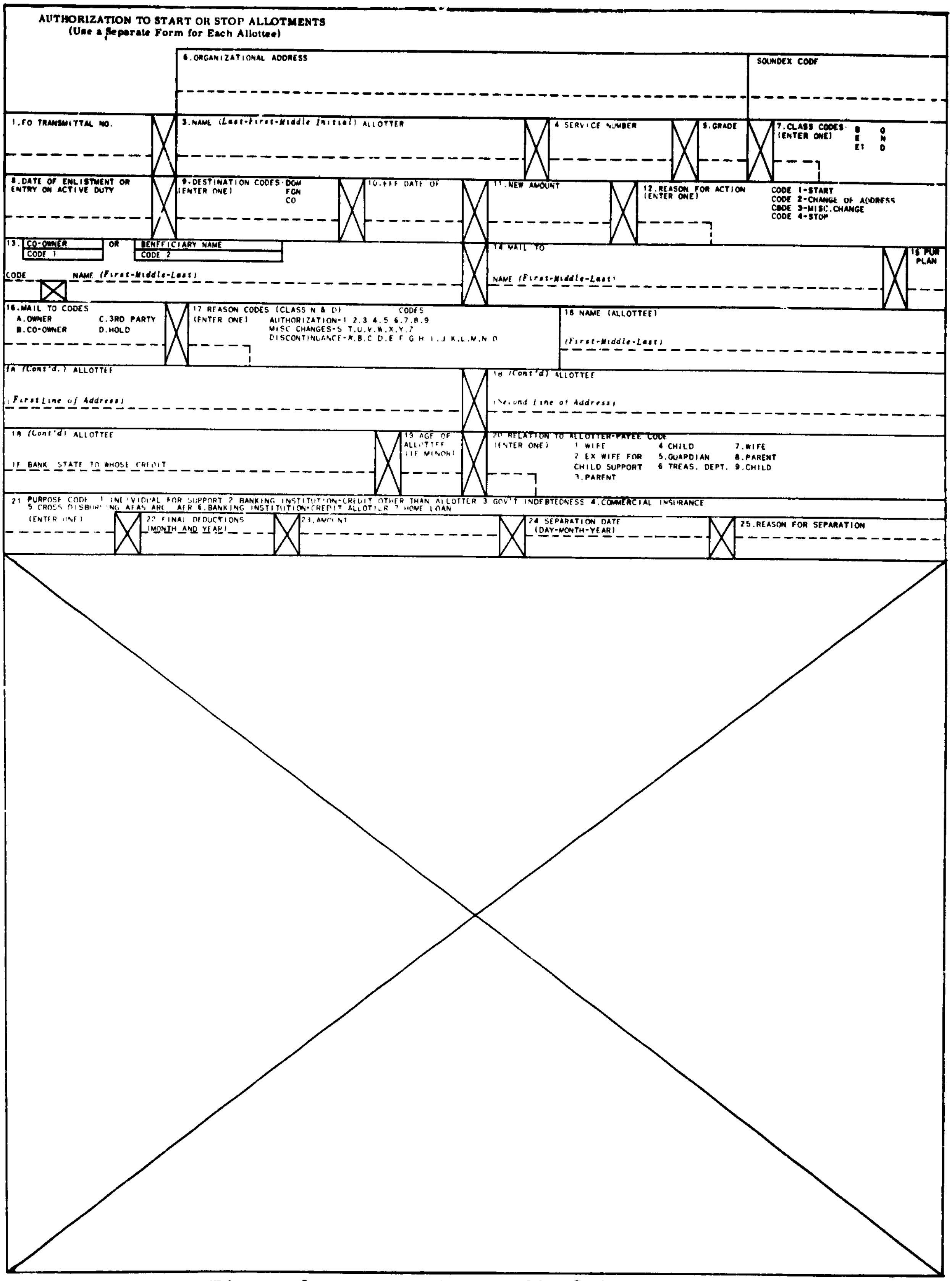


Figure 2-38 REFLECTIVITY DIAGRAM



AUTHORIZATION TO START OR STOP ALLOTMENTS
(Use a Separate Form for Each Allottee)

6. ORGANIZATIONAL ADDRESS

SOUNDEX CODE

1. FO TRANSMITTAL NO.

3. NAME (Last-First-Middle Initial) ALLOTTER

4 SERVICE NUMBER

5. GRADE

7. CLASS CODES (ENTER ONE) B E E1 O N D

8. DATE OF ENLISTMENT OR ENTRY ON ACTIVE DUTY

9. DESTINATION CODES (ENTER ONE) DOM FGN CO

10. EFF DATE OF

11. NEW AMOUNT

12. REASON FOR ACTION (ENTER ONE)

CODE 1-START
CODE 2-CHANGE OF ADDRESS
CODE 3-MISC. CHANGE
CODE 4-STOP

13. CO-OWNER CODE 1 OR BENEFICIARY NAME CODE 2

CODE NAME (First-Middle-Last)

14 MAIL TO

NAME (First-Middle-Last)

15 PUR PLAN

16. MAIL TO CODES
A. OWNER C. 3RD PARTY
B. CO-OWNER D. HOLD

17 REASON CODES (CLASS N & D) (ENTER ONE) CODES
AUTHORIZATION-1 2,3 4,5 6,7,8,9
MISC CHANGES-S T,U,V,W,X,Y,Z
DISCONTINUANCE-A,B,C D,E F G H I,J K,L,M,N O

18 NAME (ALLOTTEE)

(First-Middle-Last)

18 (Cont'd.) ALLOTTEE

(First Line of Address)

18 (Cont'd) ALLOTTEE

(Second Line of Address)

18 (Cont'd) ALLOTTEE

IF BANK STATE TO WHOSE CREDIT

19 AGE OF ALLOTTEE (IF MINOR)

20 RELATION TO ALLOTTER-PAYEE CODE (ENTER ONE)
1 WIFE 4 CHILD 7. WIFE
2 EX WIFE FOR CHILD SUPPORT 5. GUARDIAN 8. PARENT
3. PARENT 6 TREAS. DEPT. 9. CHILD

21 PURPOSE CODE 1 INDIVIDUAL FOR SUPPORT 2 BANKING INSTITUTION-CREDIT OTHER THAN ALLOTTER 3 GOV'T INDEBTEDNESS 4. COMMERCIAL INSURANCE
5 CROSS DISBURSING AFAS ARC AFR 6. BANKING INSTITUTION-CREDIT ALLOTTER 7 HOME LOAN
(ENTER ONE)

22 FINAL DEDUCTIONS (MONTH AND YEAR)

23. AMOUNT

24 SEPARATION DATE (DAY-MONTH-YEAR)

25. REASON FOR SEPARATION

Figure 2-39 TYPICAL OPTICAL SCANNING FORM

3.0 PERFORMANCE EVALUATION OF THE MODEL X-3 OPTICAL READER

The Model X-3 has not been in operation the length of time necessary to obtain extensive performance data. These extensive tests are necessary since reading accuracy statistics should be based on a large volume of input documents prepared by a variety of typists on a variety of typewriters. Accumulation of this kind of data will require several months of testing and evaluation.

Tests have been completed, however, which reveal specific performance capabilities and limitations. These were conducted while reading a limited volume of input documents. Only 64 of the 77 vocabulary characters were used in the following tests since the repertory of the output character generator used for readout was limited to this number.

3.1 CHARACTER SKEW

Variations in character skew must be expected when scanning documents prepared on typewriters because of typewriter manufacturing tolerances, bent keys and document skew during typing. A test was therefore performed to see how much skew can be tolerated on each character without loss of correct recognition.

Character skew was simulated by a clockwise and counter-clockwise rotation of the Read and Pre-read photodiode columns. Counter-clockwise rotation of the columns simulates clockwise rotation of the characters, and conversely, clockwise rotation of the columns simulates counter-clockwise character rotation. Each character was subjected to a total skew range of $\pm$ 4.5 degrees, while noting the angle at which non-recognition or substitution took place. Figure 3-1 shows the results concerning each character under test. The horizontal lines associated with every character indicate the range of correct recognition, while characters noted after certain lines identify substitutions that occurred at the angles indicated. The absence of any substitution indication means non-recognition occurred due to saturation of the output selection latches. Saturation by error bits causes complete loss of sensitivity and no recognition decision is then possible.

Based on this test, the optimum angle at which the photodiode columns are set for best reading performance is -.25 degrees. It should be noted, however, that samples used for the test were assumed to be perfectly erect which probably is not true.

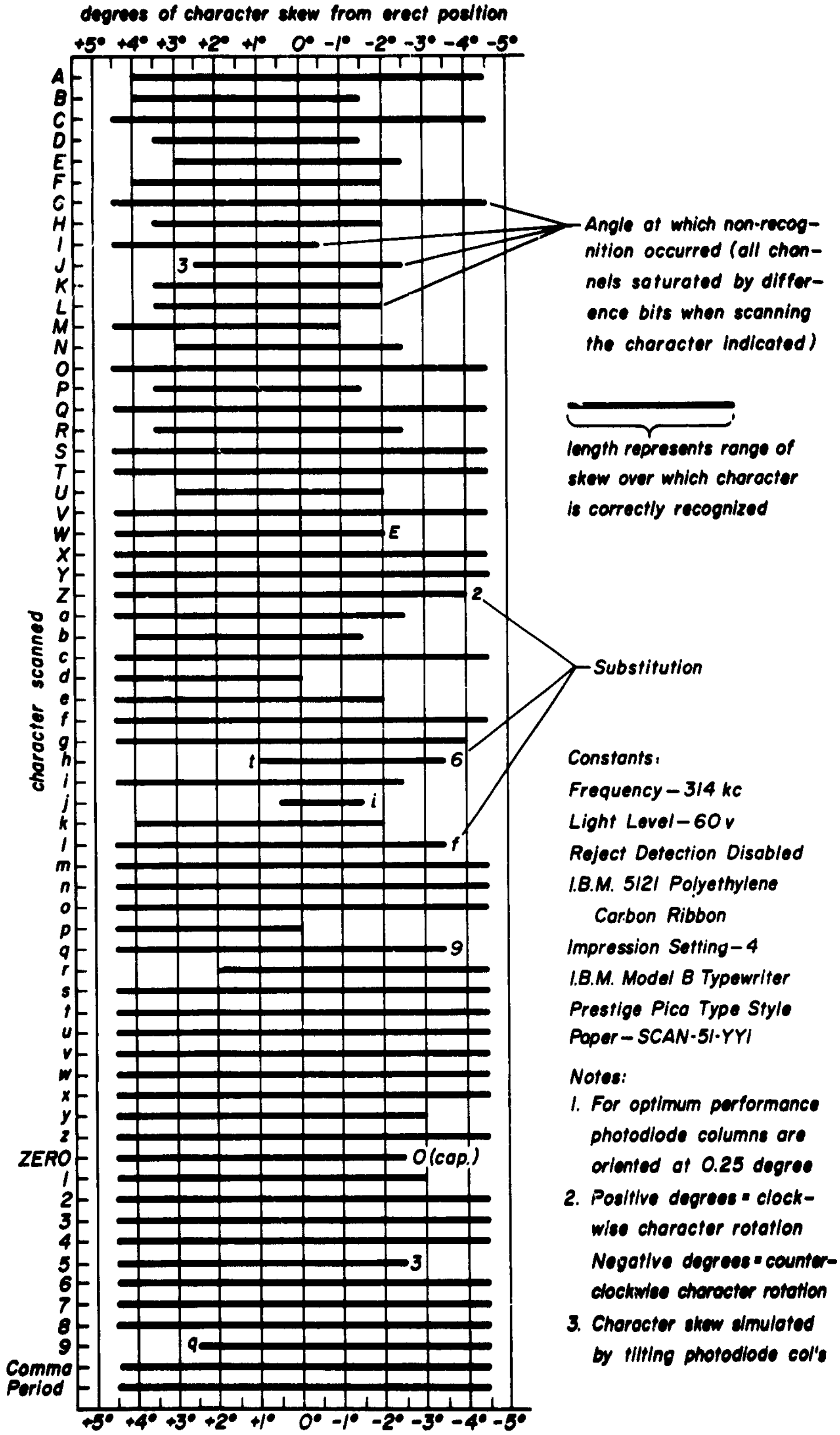


Figure 3-1 *INDIVIDUAL CHARACTER SKEW TOLERANCE*

The allowable skew variation for correct recognition of all characters is somewhat limited. However, the over-all tolerance can be increased considerably by alterations in the coding of characters identified as the limiting cases. For instance, a tolerance of ± 2 degrees could be realized by changing the coding of the following eight characters (I, J, h, i, r, p, d, and 9). A further increase in tolerance would probably require a different approach in attaining the initial data. Depending on the degree of tolerance required, character data could be recorded at different angles and then superimposed. If enough invarient video data is available, only one coding is needed. A double coding might become necessary should the character in question be skewed to the extent that it is classified into the wrong memory group by the Classification Filter or if insufficient video data remains after data superimposition has taken place.

3.2 SCANNING RATE TOLERANCE

For reliable system operation it is necessary to determine the variation in scanning rate which can be tolerated. Scanning rate and system clock frequency are directly proportional as shown in Figure 3-2, hence changes in scanning rate can be simulated by varying the system clock frequency.

For this reason a test was performed to determine the clock frequency range over which reliable recognition takes place for each individual character. A reject level of five bits was used; i.e., indicating a reject when the character scanned produced five errors in its respective channel. As in the previous chart, the horizontal lines associated with every character (Figure 3-3) indicate the frequency range over which the character is correctly recognized. Substitutions are indicated to show those characters which apparently exhibit the most similar coded characteristics as frequency or scanning rate change. Substitutions occur when the reject threshold is above the level associated with the character that was substituted. Figure 3-3 shows the frequencies at which rejects or substitutions occur for each character tested.

The present operating speed of the Model X-3 is 125 characters per second with a Document Drum speed of 62.5 RPM. This corresponds to a system clock frequency of 314 KC. A variation of ± 5 KC or approximately ± 1.6 per cent change in scanning rate can be tolerated presently.

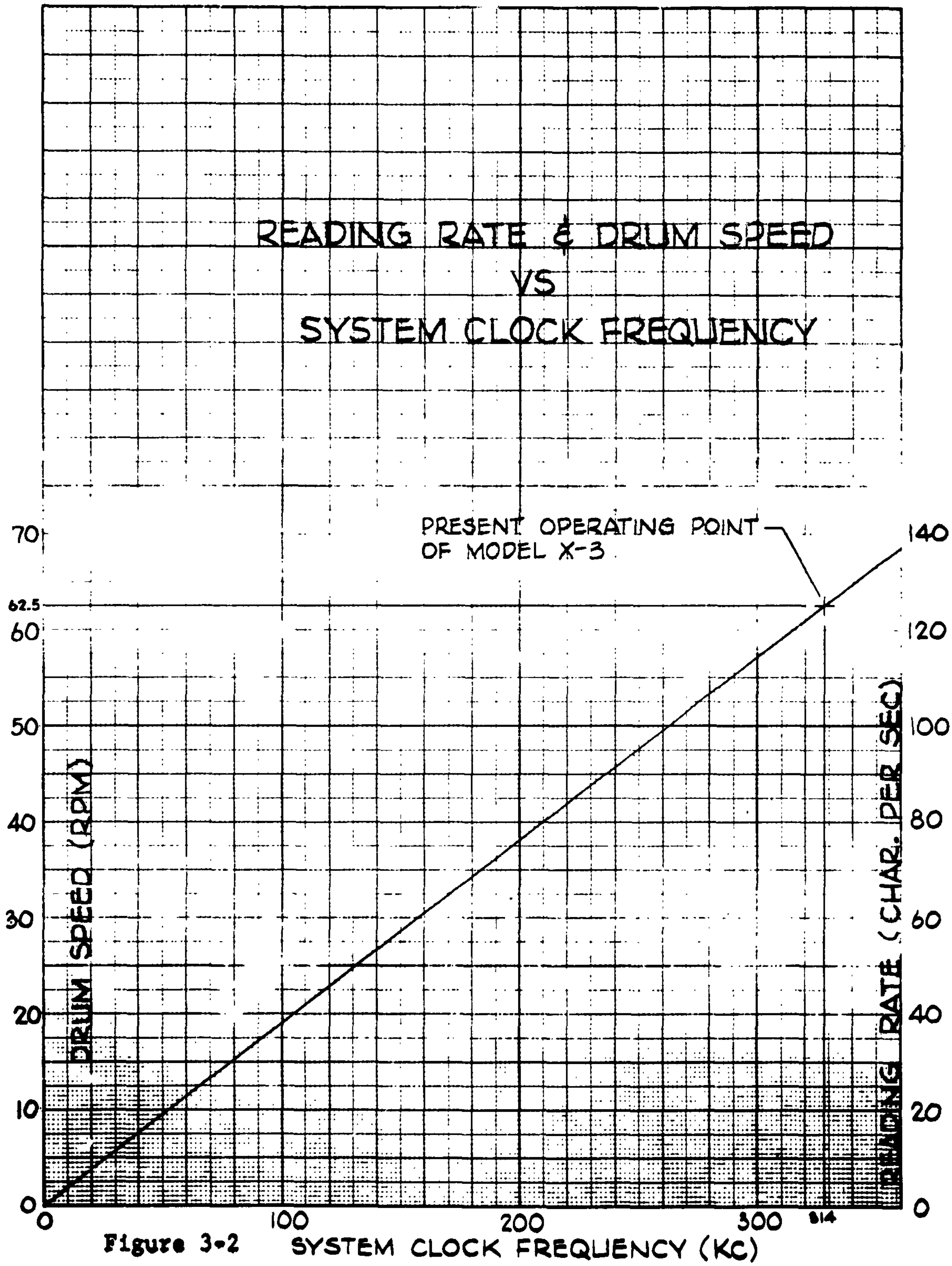

READING RATE & DRUM SPEED
VS
SYSTEM CLOCK FREQUENCY
PRESENT OPERATING POINT OF MODEL X-3
DRUM SPEED (RPM)
READING RATE (CHAR. PER SEC)
70
62.5
60
50
40
30
20
10
0
140
120
100
80
60
40
20
0
0
100
200
300
314
SYSTEM CLOCK FREQUENCY (KC)

Figure 3-2

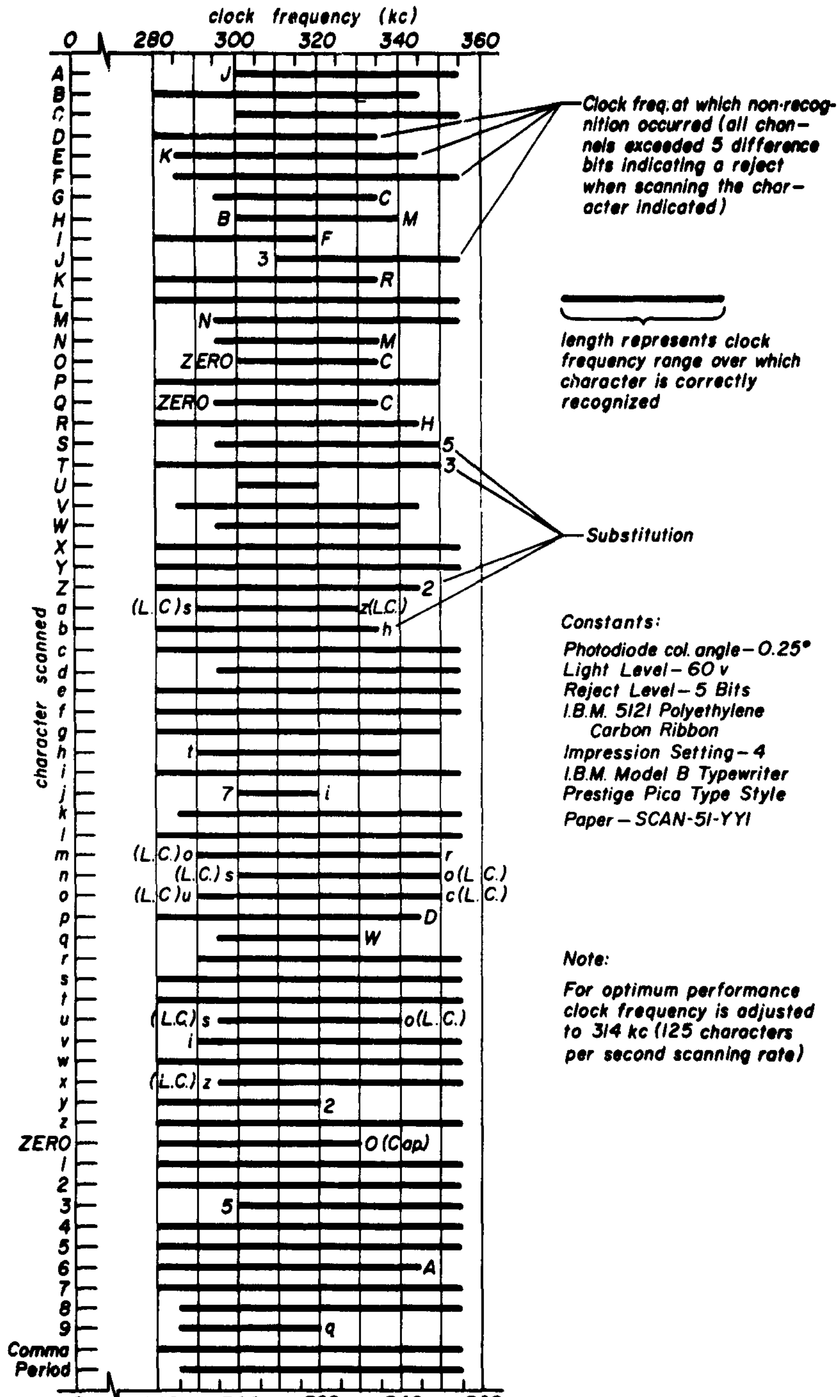


FIG. INDIVIDUAL CHARACTER CLOCK FREQUENCY TOLERANCE

Figure 3-3

The frequency tolerance can probably be expanded in most cases by investigating data for characters in the region where nonrecognition occurred, then altering the coding accordingly. In other cases, it may be necessary to code a given character as two separate characters; that is, a low scanning rate version and a high scanning rate version. This technique can be applied (as in the case of character skew) to obtain very wide operating tolerance. Frequency or scanning rate tolerance is dependent on character shape and, as a general rule, the more dependent a character coding is on vertical strokes, the more restricted is the scanning rate tolerance.

3.3 EFFECT OF REJECT THRESHOLD SETTING ON REJECT RATE

A message containing 64 vocabulary characters was used to construct a chart representing the occurrence of rejects versus setting of reject threshold control during 10 scans. Document and type quality were nearly ideal. All variables such as angle of photodiode columns and clock frequency were set to optimum values. Figure 3-4 shows the rejects and reject rates which occurred for settings of reject threshold from one to five bits. With lower reject threshold, more rejects occurred, since the requirements on character quality are more exacting. With one-bit reject threshold, the overall reject rate was 10.5 per cent. Characters rejected under these circumstances have accumulated at least one error bit in their respective output selection latch. The reject rate was zero when the threshold was increased to four bits or higher. The characters that appear with subscripts in Figure 3-4 are the characters that were rejected with the subscript indicating the number of rejects from a sample group of 10.

Since document quality was nearly ideal, no substitutions took place; therefore, no data could be obtained relating the effect of Reject Threshold Setting on Error Rate.

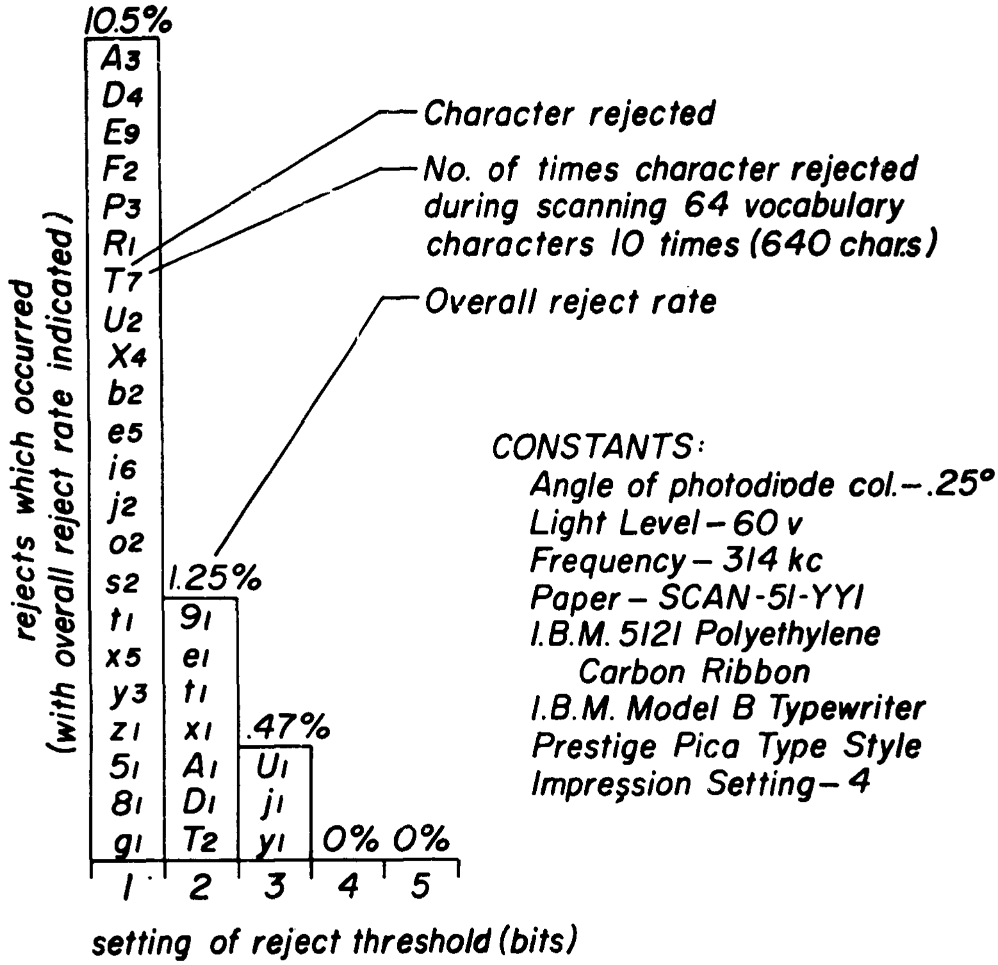


Figure 3-4 OCCURRENCE OF REJECTS VS SETTING OF REJECT THRESHOLD CONTROL

2-4-63

4.0 CONCLUSIONS

A laboratory page reading system has been constructed with a recognition capacity of at least 77 characters using the Link Reading Technique. Furthermore, the vocabulary can be increased, possibly to 100 characters or more, with multi-font capability. Using memory module substitution, the vocabulary range is virtually unlimited.

Merged and overlapping characters can be recognized,in most cases, using the Link Reading Technique.

Reliable paper handling mechanisms can be fabricated, which are not affected by normal document degradation due to field usage.

Electric typewriters equipped with polyethylene carbon ribbons, produce the best document quality for optical scanning purposes.

Use of coated paper, in general, results in better typewritten document quality than uncoated paper for optical scanning purposes.

The principal limitation on reading rate using the Link Technique, is the line finding mechanism. Upper limit on reading rate for random line spacing is estimated to be about 600 characters per second. For single line documents, the speed potential is in excess of 1,000 characters per second.

Approximately ten equally spaced columnar scans consisting of 25 rows each is an adequate character scanning resolution for vocabularies up to at least 100 characters, provided that sub-groups can be formed of 50 characters or less by means of a Classification Filter.

A prototype multifont reading machine, including paper transport, will require approximately nine months to fabricate and deliver.

5.0 RECOMMENDATIONS

Development of a line finding mechanism with random spacing capability. The Model X-3 will presently tolerate a random location of the first line on the document; however, spacing of succeeding lines must be fixed (single or double).

Further development of a reject marking device to physically mark rejected characters at high speed (at least 500 characters per second).

Development of a size normalization technique, either optical or electronic, such that single memory modules serve for different size type styles.

Development of a vocabulary repertory for page readers using the Link Reading Technique. This should be preceded by a study to determine the most popular type styles presently in use. Similar styles could then be combined with individual memory modules fabricated for the resulting style groups.

Development of error correction procedures which permit rescanning of corrected documents.